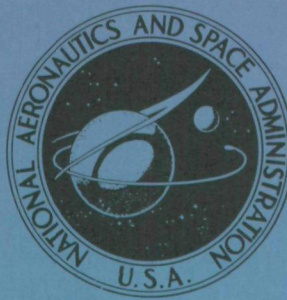


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STABILITY AND CONTROL CHARACTERISTICS
OF A MONOPLANAR MISSILE CONFIGURATION
WITH TWO LOW-PROFILE TAIL ARRANGEMENTS
AT MACH NUMBERS FROM 1.70 TO 2.86

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CONFIGURATION WITH TWO LOW-PROFILE TAIL ARRANGEMENTS AT

MACH NUMBERS FROM 1.70 TO 2.86

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SUMMARY

An experimental wind-tunnel investigation has been made to determine the longitudinal and lateral aerodynamic stability and control characteristics of two tail-fin arrangements of a monowing missile model. Both a conventional-cruciform and a low-profile tail arrangement were tested.

The results indicate that the tail surfaces of both the low-profile and the conventional-cruciform tail configurations are effective in producing pitch control. The low-profile tail arrangement exhibits relatively linear pitching-moment characteristics with no apparent pitch-up tendencies that characterize the conventional-cruciform tail. The low-profile tail configuration has a maximum variation in aerodynamic-center location with Mach number of only 3 percent; whereas, the conventional-cruciform tail has about 6 percent variation. The values of the maximum lift-drag ratio remain essentially constant and are greater at the higher Mach numbers for the low-profile tail configuration. The low-profile tail configuration is severely limited in trimmed-lift coefficient (maneuver potential) due to directional instability; however, it does have the most positive effective-dihedral parameter for the angle-of-attack and Mach number ranges. Both tail arrangements are effective in producing roll and yaw control that is accompanied by proverse yaw and roll, respectively. The conventional-cruciform tail produces the most roll and yaw control.

INTRODUCTION

The National Aeronautics and Space Administration is currently conducting aerodynamic studies of various monoplane missile configurations in order to provide an insight into the potential for improving conformal carriage, performance, and maneuverability for future air-launched missiles. A promising concept from the conformal-carriage standpoint (refs. 1 and 2) utilizes interdigitated conventional-cruciform tail surfaces since they require less space in the vertical and horizontal planes than conventional vertical and horizontal tails with the same surface area ("+" arrangement). However, several undesirable aerodynamic characteristics have been associated with this concept. Primarily, these are nonlinear pitching-moment characteristics (pitch-up tendencies) and inadequate directional stability for an assumed center-of-gravity location that is consistent with good supersonic longitudinal performance (ref. 3).

The purpose of this paper is to describe an experimental wind-tunnel investigation that has been conducted in an effort to evaluate a monoplanar missile configuration with lower profile tail fins than one with an interdigitated conventional-cruciform tail arrangement. Hopefully, a better compromise between both good directional stability and good longitudinal aerodynamic stability and control characteristics including more linear pitching-moment curves might be realized. In addition, a more viable conformal-carriage missile candidate might evolve. Tests included a comparison of two tail-fin arrangements on a monoplanar missile configuration. One tail arrangement included conventional-cruciform tail fins interdigitated to the wings ("x" arrangement). The other was a modification of the cruciform arrangement that resulted in reducing the included angle between the fins with respect to the horizontal plane (low-profile tail concept). The low-profile tail concept offers the potential of a more efficient external-carriage interface between an airplane and a missile since the tail surfaces require less space in the vertical plane.

The tests were conducted in the Langley Unitary Plan wind tunnel at Mach numbers from 1.70 to 2.86. The nominal angle-of-attack range was -4° to 26° and the nominal angle-of-sideslip range was about -4° to 6° . The test Reynolds number varied from 3.3×10^6 to $6.6 \times 10^6/\text{m}$ (1.0×10^6 to $2.0 \times 10^6/\text{ft}$). The results include the effects of various configuration components and the effects of low-profile and conventional-cruciform tail arrangements on the longitudinal and lateral aerodynamic stability and control characteristics of a monoplanar missile configuration. For both arrangements, the tail fins were deflected to obtain pitch, yaw, and roll control, respectively.

SYMBOLS

The aerodynamic coefficient data are referred to the body-axis system except for lift and drag which are referred to the stability-axis system. The moment reference is located 51.51 cm (20.28 in.) aft of the model nose (60.0 percent of the body length).

Measurements and calculations were made in U.S. Customary Units. Measurements are presented in the International System of Units (SI) with the equivalent values given parenthetically in U.S. Customary Units. (See ref. 4.)

b wing span, 24.486 cm (9.640 in.)

C_A axial-force coefficient, $\frac{\text{Axial force}}{qS}$

$C_{A,b}$ base axial-force coefficient, $\frac{\text{Base axial force}}{qS}$

C_D drag coefficient, $\frac{\text{Drag}}{qS}$

$C_{D,b}$	base drag coefficient, $\frac{\text{Base drag}}{qS}$
$C_{D,o}$	drag coefficient at $\alpha = 0^\circ$, $\frac{\text{Drag}}{qS}$
C_L	lift coefficient, $\frac{\text{Lift}}{qS}$
$C_{L,\text{trim}}$	trimmed-lift coefficient at $C_m = 0$, $\frac{\text{Trimmed lift}}{qS}$
$C_{L\alpha}$	lift-curve slope near $\alpha = 0^\circ$, per deg
C_l	rolling-moment coefficient, $\frac{\text{Rolling moment}}{qSb}$
$C_{l\beta}$	effective-dihedral parameter, $\left(\frac{\Delta C_l}{\Delta \beta} \right)_{\beta=0^\circ, 2^\circ}$
C_m	pitching-moment coefficient, $\frac{\text{Pitching moment}}{qS l}$
$C_{m\delta}$	pitch-control effectiveness of four tail fins at $\alpha = 0^\circ$, per deg of deflection for tail-fin deflections of 0° and -10°
C_N	normal-force coefficient, $\frac{\text{Normal force}}{qS}$
C_n	yawing-moment coefficient, $\frac{\text{Yawing moment}}{qSb}$
$C_{n\beta}$	directional-stability parameter, $\left(\frac{\Delta C_n}{\Delta \beta} \right)_{\beta=0^\circ, 2^\circ}$
C_Y	side-force coefficient, $\frac{\text{Side force}}{qS}$

$C_{Y\beta}$	side-force parameter, $\left(\frac{\Delta C_Y}{\Delta \beta}\right)_{\beta=0^\circ, 2^\circ}$
L/D	lift-drag ratio
l	reference body length, 85.852 cm (33.800 in.)
M	Mach number
q	free-stream dynamic pressure, Pa (lb/ft ²)
S	wing area including body center-line intercepts, 0.064933 m ² (0.698965 ft ²)
x_{ac}	distance of aerodynamic center from model nose at $\alpha = 0^\circ$, percent of reference body length
x_{cg}	distance of center of gravity from model nose, percent of reference body length
α	angle of attack, deg
β	angle of sideslip, deg
δ_{pitch}	pitch-control deflection of four tail fins (negative with leading edge down), deg
δ_{roll}	differential roll-control deflection of individual tail fins deflected the indicated amount (positive to provide a clockwise rotation as viewed from rear), deg
δ_{yaw}	yaw-control deflection of four tail fins (negative with leading edge left), deg

Model components:

B	body alone
T _{3C}	tail fins, conventional cruciform
T _{3LP}	tail fins, low profile
W	wing

Subscripts:

max	maximum
trim	trimmed conditions

APPARATUS AND TESTS

Wind Tunnel

The investigation was conducted in the low Mach number test section of the Langley Unitary Plan wind tunnel, which is a variable-pressure, continuous-flow facility. The test section is approximately 2.13 m (7 ft) long and 1.22 m (4 ft) square. The nozzle leading to the test section is of the asymmetric sliding-block type, which permits a continuous variation in Mach number from about 1.5 to 2.9.

Model

Dimensional details of the model are shown in figure 1, and model photographs are shown as figure 2. The cylindrical body had a length-diameter ratio of 13 with a 3.0-caliber ogive nose. The model had monoplanar delta-planform wings with beveled leading and trailing edges. The four tail fins had slab cross sections with beveled leading and trailing edges. The model had two tail-fin configurations: (1) a conventional-cruciform tail arrangement (interdigitated to the monowing) with fins in planes inclined 45° to the horizontal and vertical planes; (2) a modified-cruciform tail arrangement with the fins in planes inclined 22.5° to the horizontal and 67.5° to the vertical planes (low-profile tail fins). For both tail configurations the four tail fins were used to provide pitch, yaw, and roll control, respectively.

Test Conditions

Tests were performed at the following tunnel conditions:

Mach number	Stagnation temperature		Stagnation pressure		Reynolds number	
	K	°F	kPa	psfa	per m	per ft
1.70	339	150	28.2 to 56.4	589 to 1178	3.3×10^6 to 6.6×10^6	1.0 to 2.0
2.16	339	150	51.4 to 68.5	1073 to 1430	4.9×10^6 to 6.6×10^6	1.5 to 2.0
2.36	339	150	75.7	1580	6.6×10^6	2.0
2.86	339	150	98.4	2056	6.6×10^6	2.0

The Reynolds number for all Mach numbers was $6.6 \times 10^6/\text{m}$ ($2.0 \times 10^6/\text{ft}$) except for maximum tail deflections ($\delta_{\text{pitch}} = -30^\circ$) where the Reynolds number was reduced at the low supersonic Mach numbers because of axial-force limits.

The dew point was maintained low enough to insure negligible condensation effects. All tests were performed with boundary-layer transition strips on the

body 3.05 cm (1.20 in.) aft of the nose and 1.02 cm (0.40 in.) aft of the leading edges measured streamwise on both sides of the wing and tail surfaces. The transition strips were approximately 0.157 cm wide (0.062 in.) and were composed of No. 50 sand grains sprinkled in acrylic plastic.

Measurements

Aerodynamic forces and moments on the model were measured by means of a six-component electrical strain-gage balance which was housed within the model. The balance was attached to a sting which, in turn, was rigidly fastened to the tunnel-support system. Balance-chamber pressure or base pressure was measured by means of a single static-pressure orifice located in the vicinity of the balance.

Corrections

The angles of attack and sideslip were corrected for deflection of the balance and sting due to aerodynamic loads. Also, angles of attack were corrected for tunnel-flow misalignment. The drag and axial-force coefficients data were adjusted to free-stream conditions acting over the model base. Typical values of base axial-force and drag coefficients are presented in figure 3.

PRESENTATION OF RESULTS

The results of this investigation are presented in the following figures:

	Figure
Effect of model components on longitudinal aerodynamic characteristics for low-profile and conventional-cruciform tail configurations	4
Pitch-control characteristics:	
Low-profile tail	5
Conventional-cruciform tail	6
Summary of longitudinal aerodynamic characteristics	7
Comparison of variations of trimmed-lift coefficient with center-of-gravity location for low-profile and conventional-cruciform tail configurations	8
Comparison of trim characteristics for the two tail configurations at $\delta_{pitch} = -20^\circ$	9
Lateral characteristics with sideslip angle:	
Low-profile tail	10
Conventional-cruciform tail	11
Effect of pitch control on lateral parameters:	
Low-profile tail	12

Conventional-cruciform tail	13
Effect of model components on lateral parameters for low-profile and conventional-cruciform tail configurations	14
Summary of lateral- and directional-stability parameters at $\alpha \approx 0^\circ$. . .	15
Roll-control characteristics:	
Low-profile tail	16
Conventional-cruciform tail	17
Yaw-control characteristics:	
Low-profile tail	18
Conventional-cruciform tail	19
Summary of roll- and yaw-control characteristics at $\alpha \approx 0^\circ$	20

RESULTS AND DISCUSSION

Longitudinal Aerodynamic Characteristics

The effects of model components on the longitudinal aerodynamic characteristics of the model including the effects of the conventional-cruciform and low-profile tail arrangements are presented in figure 4. Generally, there is an increase in lift-curve slope with increase in angle of attack due to vortex lift for the partial and complete configurations. The low-profile tail configuration provides the greatest lift coefficient only for angles of attack below 10° except at $M = 1.70$. This tail arrangement produces the most linear pitching-moment characteristics and for the selected moment center provides the most static margin except at $M = 1.70$. In addition, the low-profile tail reduces or eliminates the pitch-up ($\alpha \approx 8^\circ$ to 12°) that is characteristic of a monowing missile configuration with an interdigitated cruciform "x" tail arrangement. (See refs. 1 and 2.)

Pitch-control characteristics of the tail fins are presented in figures 5 and 6 for both the low-profile and conventional-cruciform tail arrangements, respectively. The tail surfaces of both configurations are effective in producing pitch control throughout the angle-of-attack and Mach number ranges. The low-profile tail produces slightly more pitch control at the higher Mach numbers, and its pitch curves are relatively linear and become more linear as the Mach number increases with no tendency for pitch-up. In figure 6 the conventional-cruciform tail arrangement produces relatively large nonlinear pitching-moment characteristics due to the adverse effects of the wing wake. This nonlinearity characterized as a pitch-up tendency is typical of a monowing missile configuration with interdigitated cruciform tails at low supersonic Mach numbers. However, this pitch-up tendency (nonlinearity) tends to decrease with increasing Mach number. A comparison of the results shown in figures 5 and 6 for common pitch deflections indicate that the low-profile tail configuration develops the highest lift coefficient for a given angle of attack and the lowest drag.

A summary of the longitudinal aerodynamic characteristics for both tail configurations is presented in figure 7. This figure indicates the usual decrease of $-C_{m\delta}$, $C_{L\alpha}$, and $C_{D,o}$ with increase in Mach number. The values of $(L/D)_{\max}$

for the low-profile tail configuration remain essentially constant and are greater at the higher Mach numbers. The aerodynamic-center location, determined near zero lift, has a maximum variation with Mach number of about 6 percent for the conventional-cruciform tail; whereas, the variation is only 3 percent for the low-profile tail configuration.

Variations of the trimmed-lift coefficient with center-of-gravity location for both tail arrangements, including a $C_{n\delta} = 0$ boundary curve for a tail

deflection of 0° , are presented in figure 8. The data indicate that the low-profile tail configuration is severely limited in trimmed-lift coefficient (maneuver potential) due to directional instability. However, based on the assumption that the directional-stability criteria is met for the two tail arrangements, this figure shows the maximum trimmed-lift coefficients obtainable with the indicated pitch-control deflections at various center-of-gravity locations. Thus, the aerodynamic potential for maneuverability or instantaneous normal acceleration of these two tail configurations can be ascertained on the basis of excess lift available over that required for the missile in level flight.

The foregoing trim results represent general trends and have been presented without a particular application to some tactical mission. For purposes of further analysis, the results will be evaluated with the view that a mission is involved for which large turning forces (e.g., pull-ups or a pitch-up maneuver from level flight) are required. In order that a comparison could be made between the two tail arrangements, an arbitrary tail pitch-control deflection of -20° was selected. Figure 9 illustrates the trim characteristics, including the trimmed lift-drag ratio, as functions of center-of-gravity location for this pitch deflection. In each case, the curves were terminated at the highest test angle of attack as they approached rearward center-of-gravity locations at which neutral stability would have occurred (e.g., zero static margin, center of gravity on the aerodynamic center). Consequently, the magnitudes of the quantities shown in figure 9 correspond to the largest trim values. The angle-of-attack variations shown in this figure are of interest only to indicate the attitude required for each of the configurations to develop the simulated turning forces represented by the values of the trimmed-lift coefficients. When making aerodynamic stability and control comparisons, one must keep in mind that the directional-stability parameter of each tail configuration must also be considered along with its respective trimmed-lift coefficient. These coefficients indicate that the low-profile tail surfaces are much more effective than the conventional-cruciform arrangement when considered from the standpoint of ability to produce lift at the most rearward center-of-gravity locations.

Lateral Aerodynamic Characteristics

The lateral aerodynamic characteristics as a function of sideslip angle at various angles of attack for the low-profile and conventional-cruciform tail

configurations with zero-control deflections are presented in figures 10 and 11, respectively. These data are shown primarily to indicate the linearity of the coefficients with sideslip angles, since all lateral parameters were obtained from incremental results of tests made through the angle-of-attack range at $\beta = 0^\circ$ and 2° . The results were generally linear for the lower angles of attack and indicated that the comparative results shown for the lateral parameters at these angles of attack are valid.

The effect of pitch control for both tail configurations is presented in figures 12 and 13. Generally, for either configuration the deflection ($\delta_{pitch} = -20^\circ$) increased the directional-stability parameter for most of the angle-of-attack range except at the lowest Mach numbers. For the lower angles of attack the pitch deflection decreased the positive effective-dihedral parameter.

The effects of model components on the lateral parameters, including the effects of the two tail arrangements, are presented in figure 14. For the assumed center of gravity (0.601) which is consistent with good supersonic longitudinal performance, only the configurations with the conventional-cruciform tail arrangement are directionally stable throughout the Mach number range; whereas, the low-profile tail is directionally stable for only $M = 1.70$. Generally, the low-profile tail produces the greatest positive effective-dihedral parameter of any other configuration for the entire angle-of-attack and Mach number ranges.

A summary of the lateral- and directional-stability parameters for the two tail configurations is presented in figure 15. The conventional-cruciform tail configuration is directionally stable throughout the test Mach number range; whereas, the low-profile tail becomes unstable beyond approximately $M = 2.12$. For $\alpha \approx 0^\circ$ the low-profile tail has a slightly more positive effective-dihedral parameter at the higher Mach numbers than the conventional-cruciform tail.

A possible solution to make the low-profile tail configuration a more viable conformal-carriage candidate by providing it with more directional stability might be the installation of a pair of nose strakes or side fairings. Nose strakes tend to improve directional stability with increases in angle of attack; however, they do have small destabilizing effects longitudinally that could have a beneficial effect by increasing the trimmed-lift coefficient. In addition, the low-profile tail could be used in conjunction with a stability-augmentation system (adaptive-control system) provided that adequate yaw control is available and the directional-instability boundary at the maximum trim angles of attack can be tolerated.

The roll- and yaw-control characteristics for each of the tail arrangements are presented in figures 16 through 19. A summary of these characteristics is presented in figure 20. Both tail arrangements are effective throughout the angle-of-attack and Mach number ranges in producing roll control with the conventional-cruciform tail providing the greatest roll effectiveness and proverse yaw. A comparison of the data in figures 18 and 19 indicates that the two tail arrangements are effective in producing yaw control. The conventional-cruciform tail produces the most yaw control which is accompanied by proverse roll at the higher angles of attack.

CONCLUSIONS

An experimental wind-tunnel investigation has been made to determine the longitudinal and lateral aerodynamic stability and control characteristics of two tail-fin arrangements of a monowing missile model. Both a conventional-cruciform and a low-profile tail arrangement were tested. The following results were obtained from the investigation:

1. The tail surfaces of both the low-profile and the conventional-cruciform tail configurations are effective in producing pitch control. The low-profile tail arrangement exhibits relatively linear pitching-moment characteristics with no apparent pitch-up tendencies that characterize the conventional-cruciform tail.

2. The low-profile tail configuration has a maximum variation in aerodynamic-center location with Mach number of only 3 percent; whereas, the conventional-cruciform tail has about 6 percent variation. For the low-profile tail configuration the values of the maximum lift-drag ratio remain essentially constant and are greater at the higher Mach numbers.

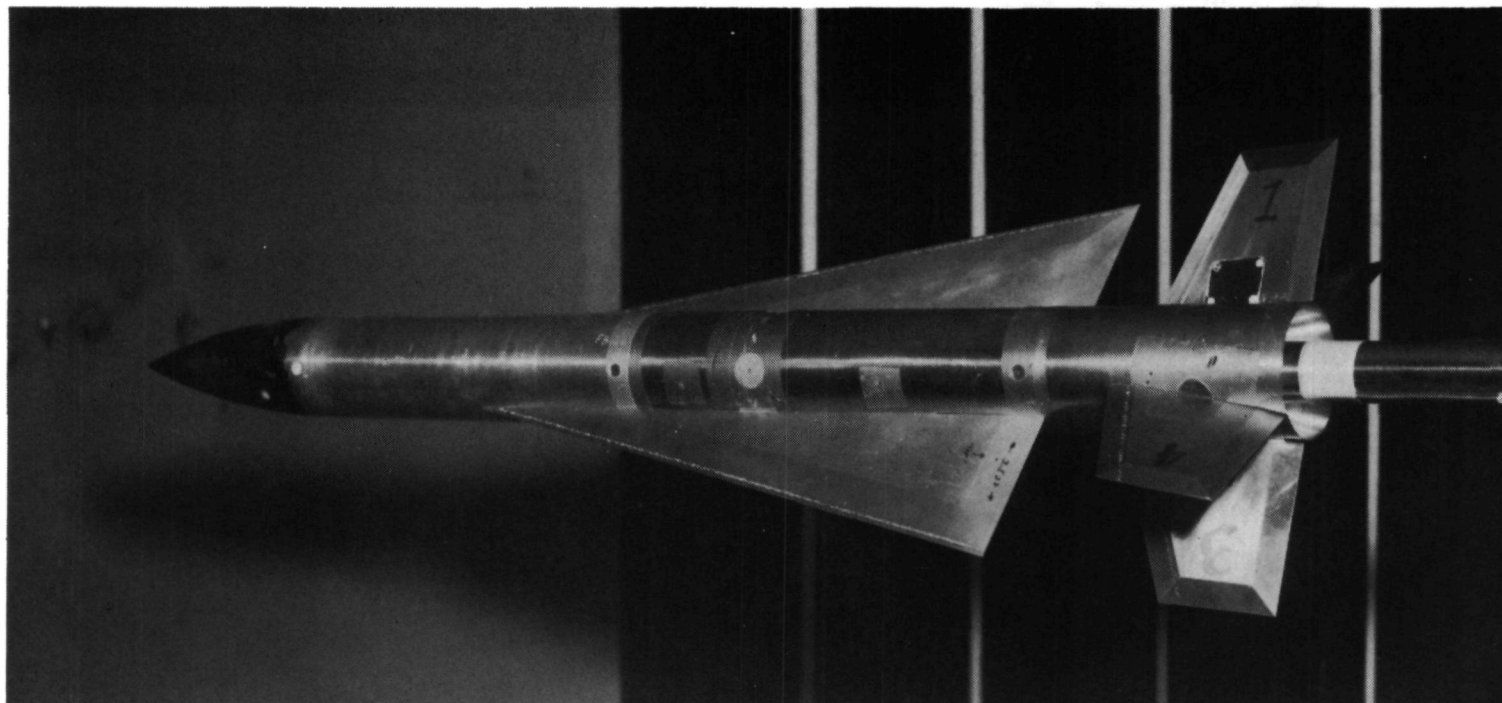
3. The low-profile tail configuration is severely limited in trimmed-lift coefficient (maneuver potential) due to directional instability; however, it does have the most positive effective-dihedral parameter for the angle-of-attack and Mach number ranges.

4. Both tail arrangements are effective in producing roll and yaw control that is accompanied by proverse yaw and roll, respectively. The conventional-cruciform tail produces the most roll and yaw control.

Langley Research Center
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Hampton, VA 23665
June 15, 1977

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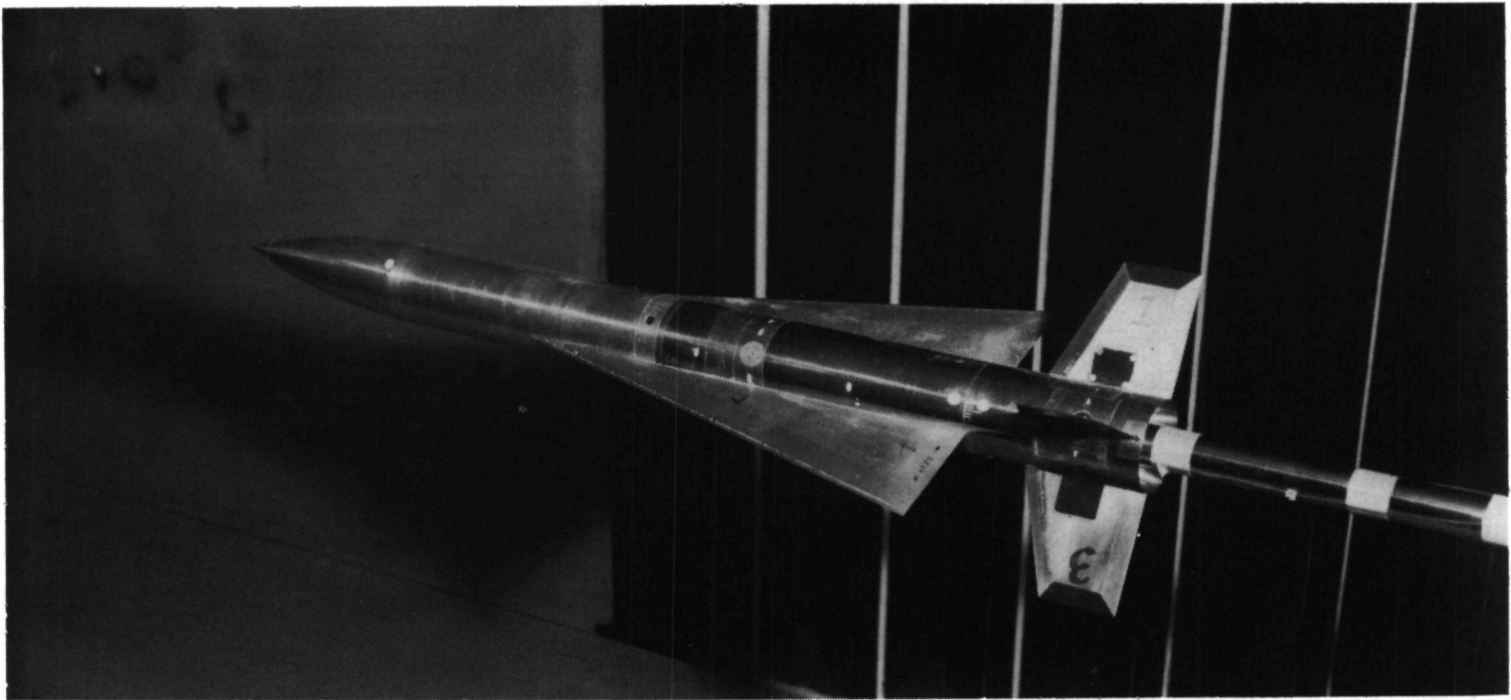
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(a) Low-profile tail configuration.

Figure 2.- Model photographs.



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(b) Conventional-cruciform tail configuration.

Figure 2.- Concluded.

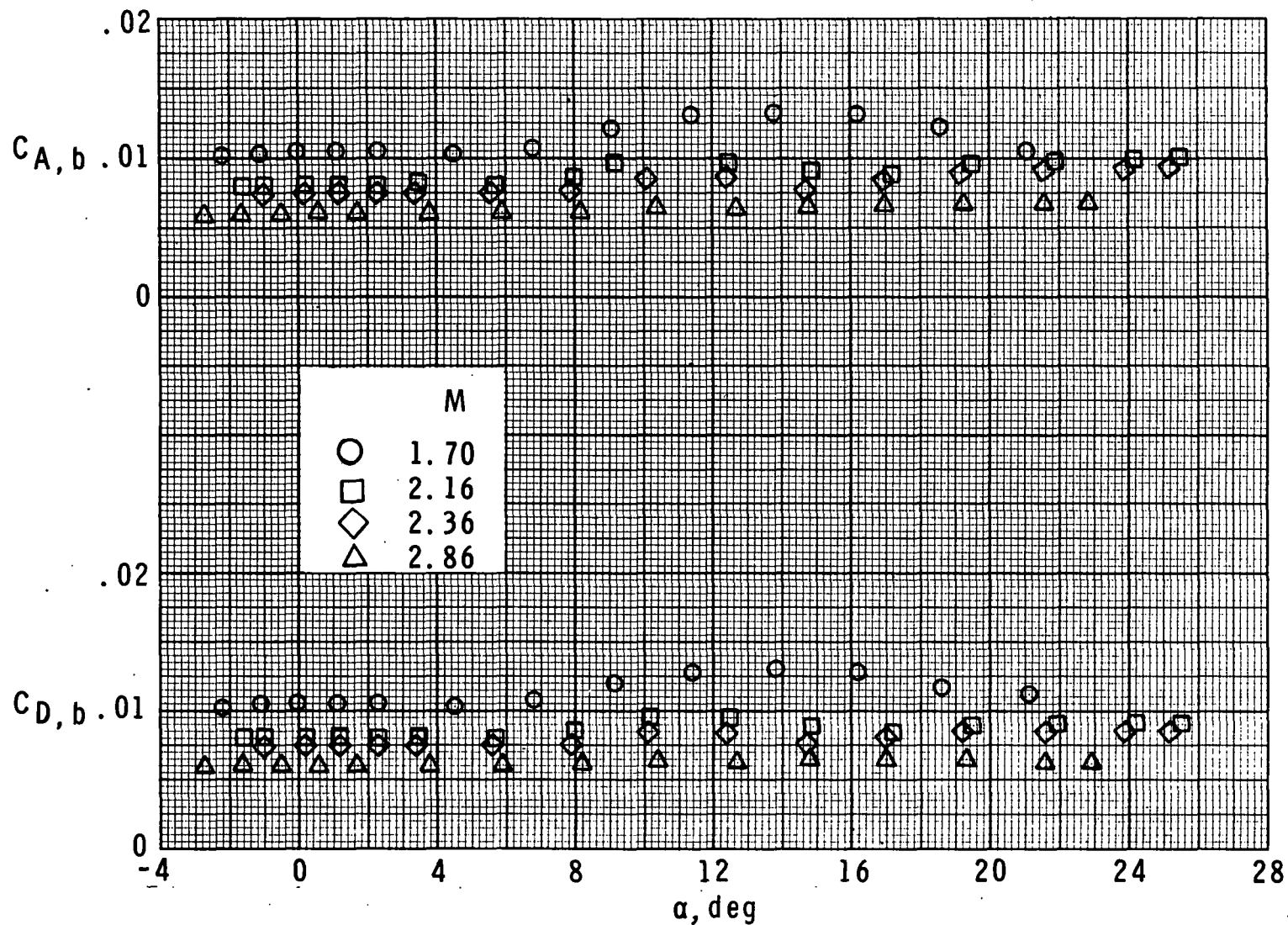
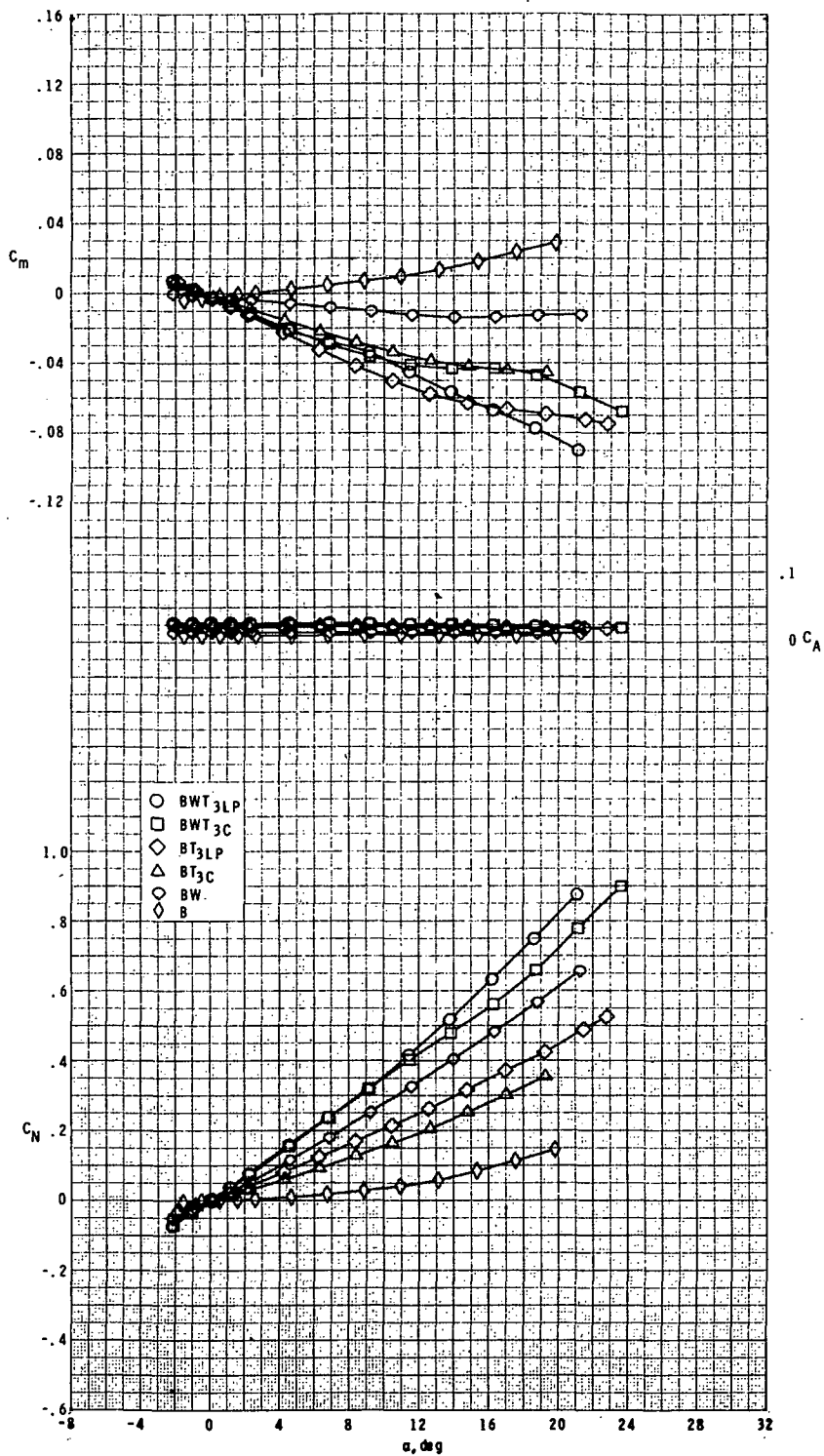
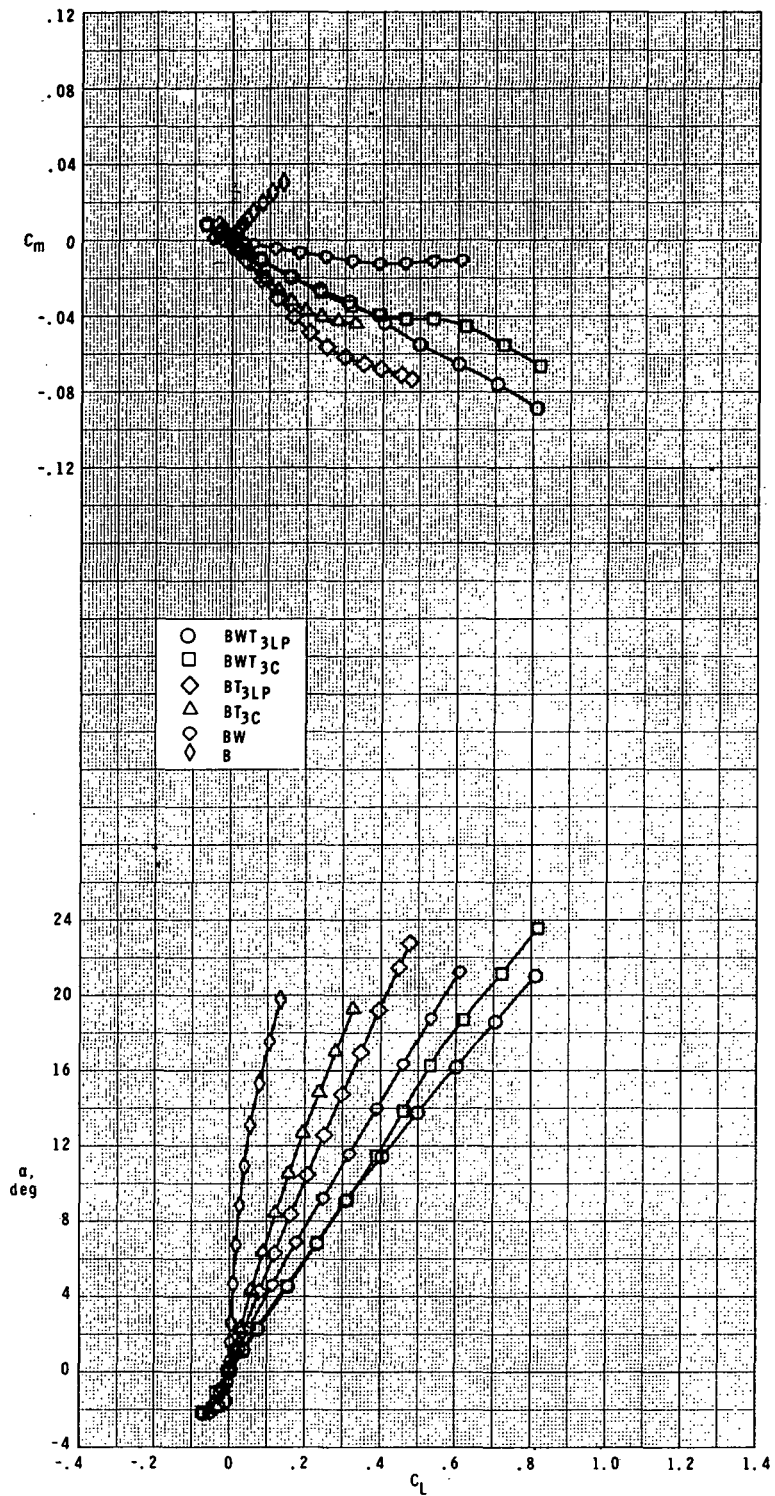


Figure 3.- Typical variation of $C_{A,b}$ and $C_{D,b}$ with angle of attack for either tail configuration.



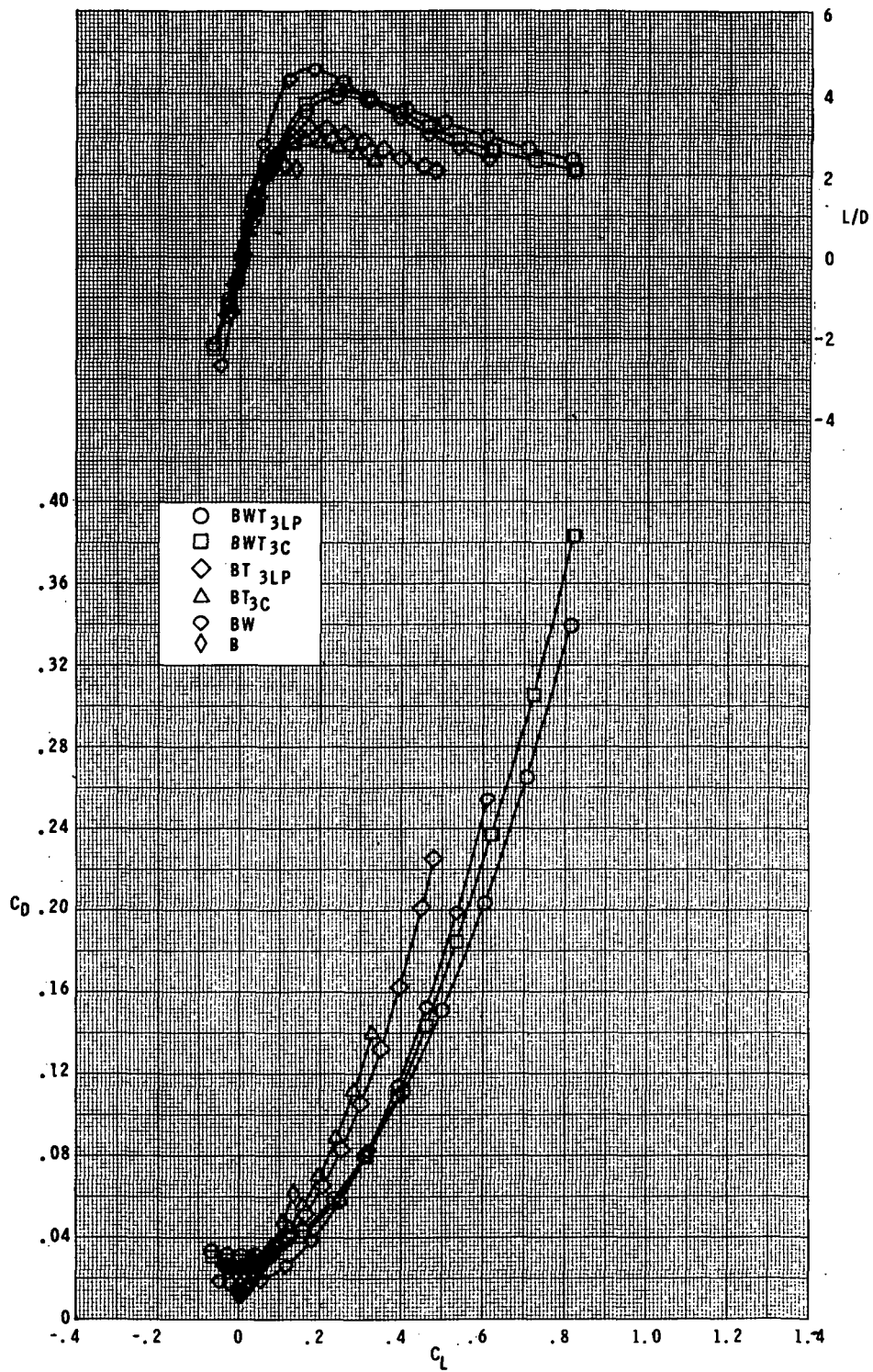
(a) $M = 1.70$.

Figure 4.- Effect of model components on longitudinal aerodynamic characteristics for low-profile and conventional-cruciform tail configurations.



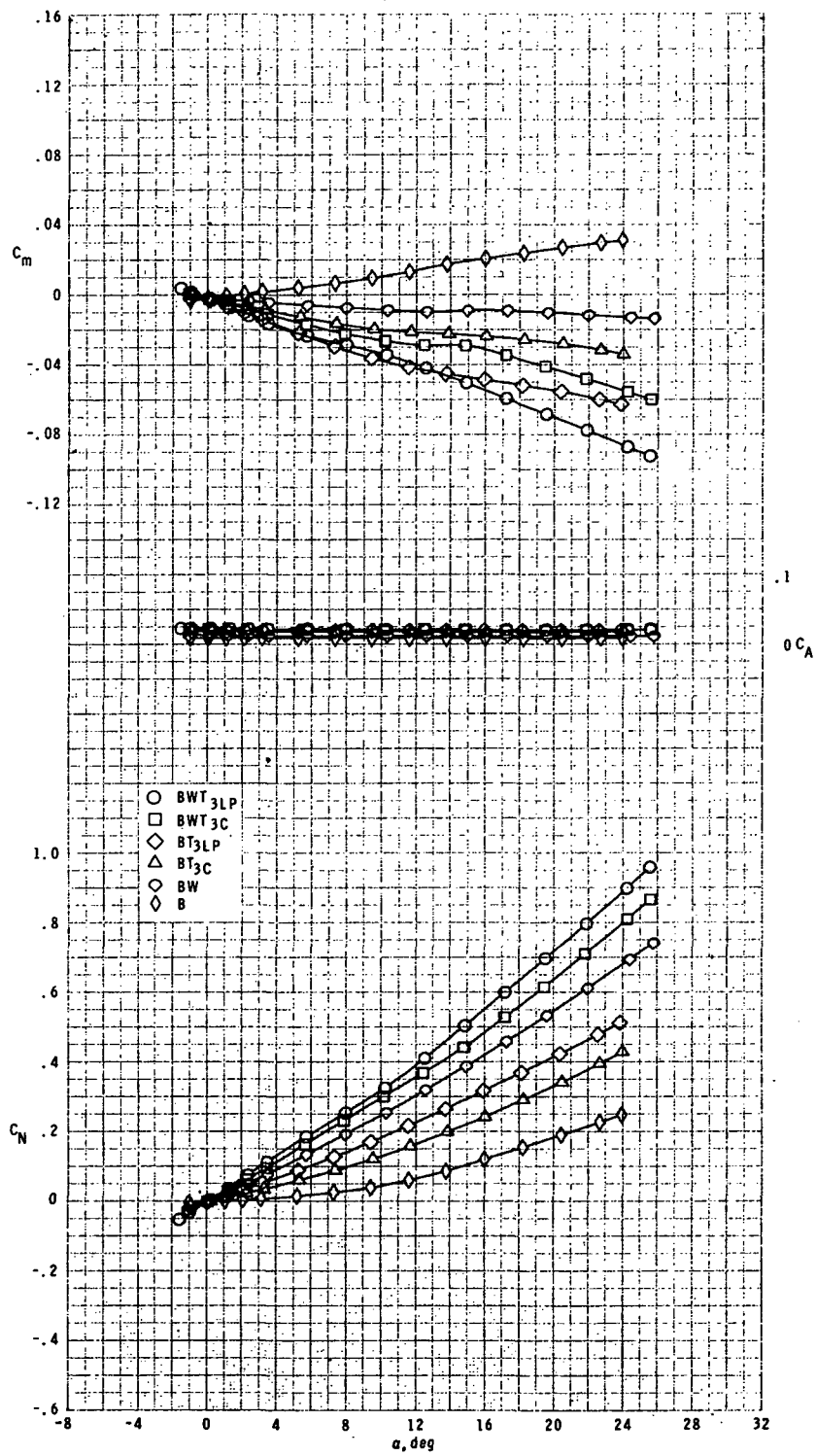
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Figure 4.- Continued.



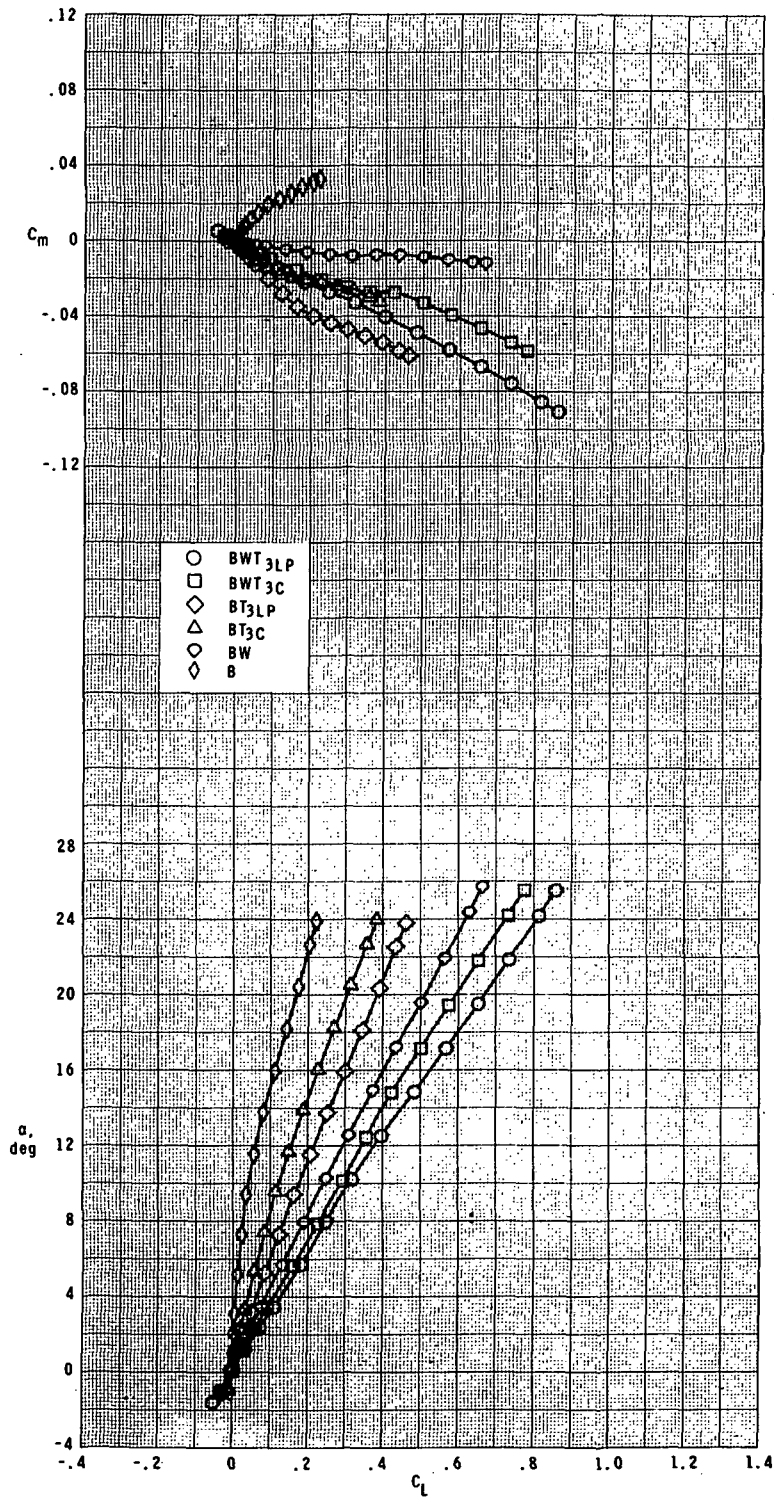
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Figure 4.- Continued.



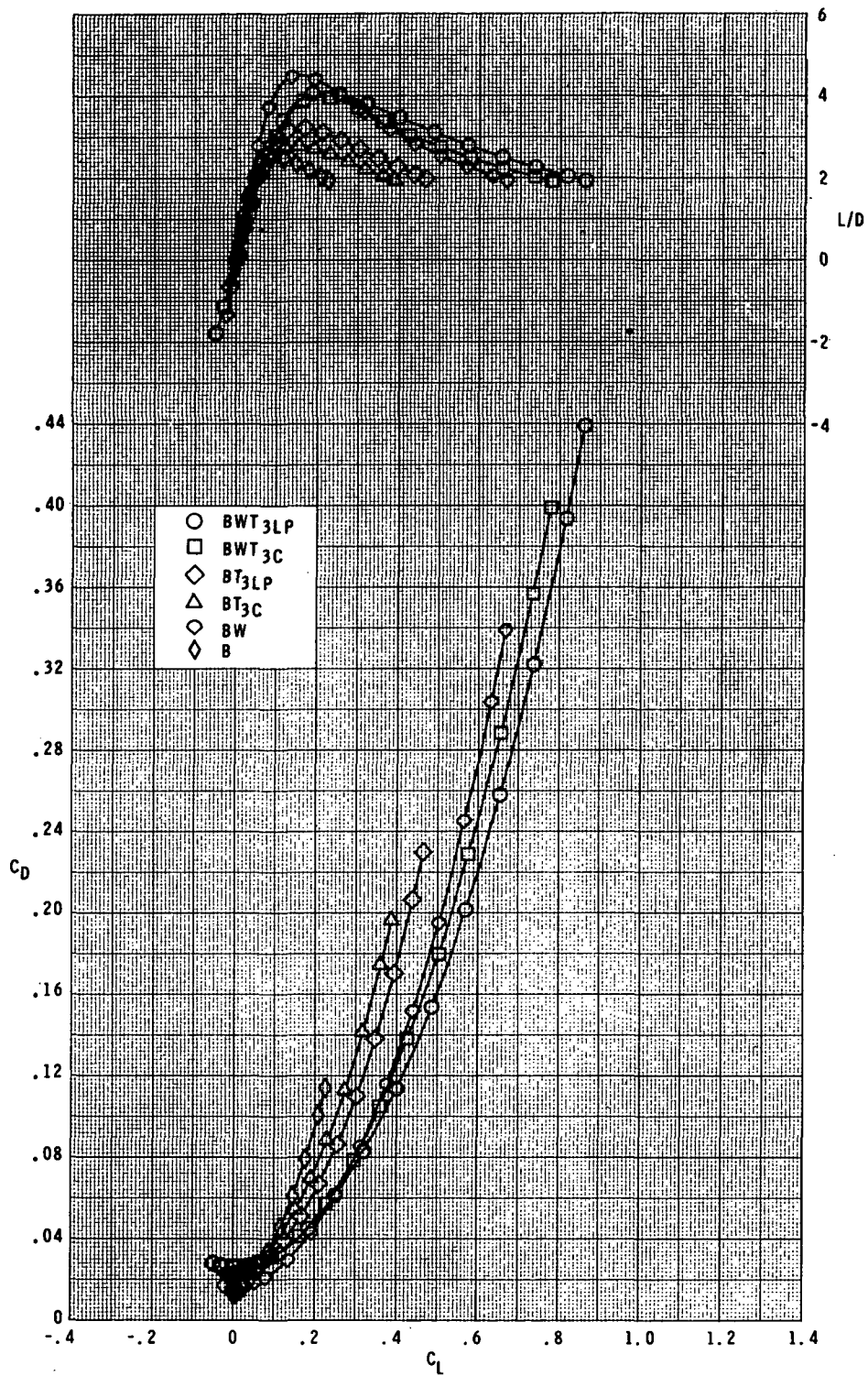
(b) $M = 2.16$.

Figure 4.- Continued.



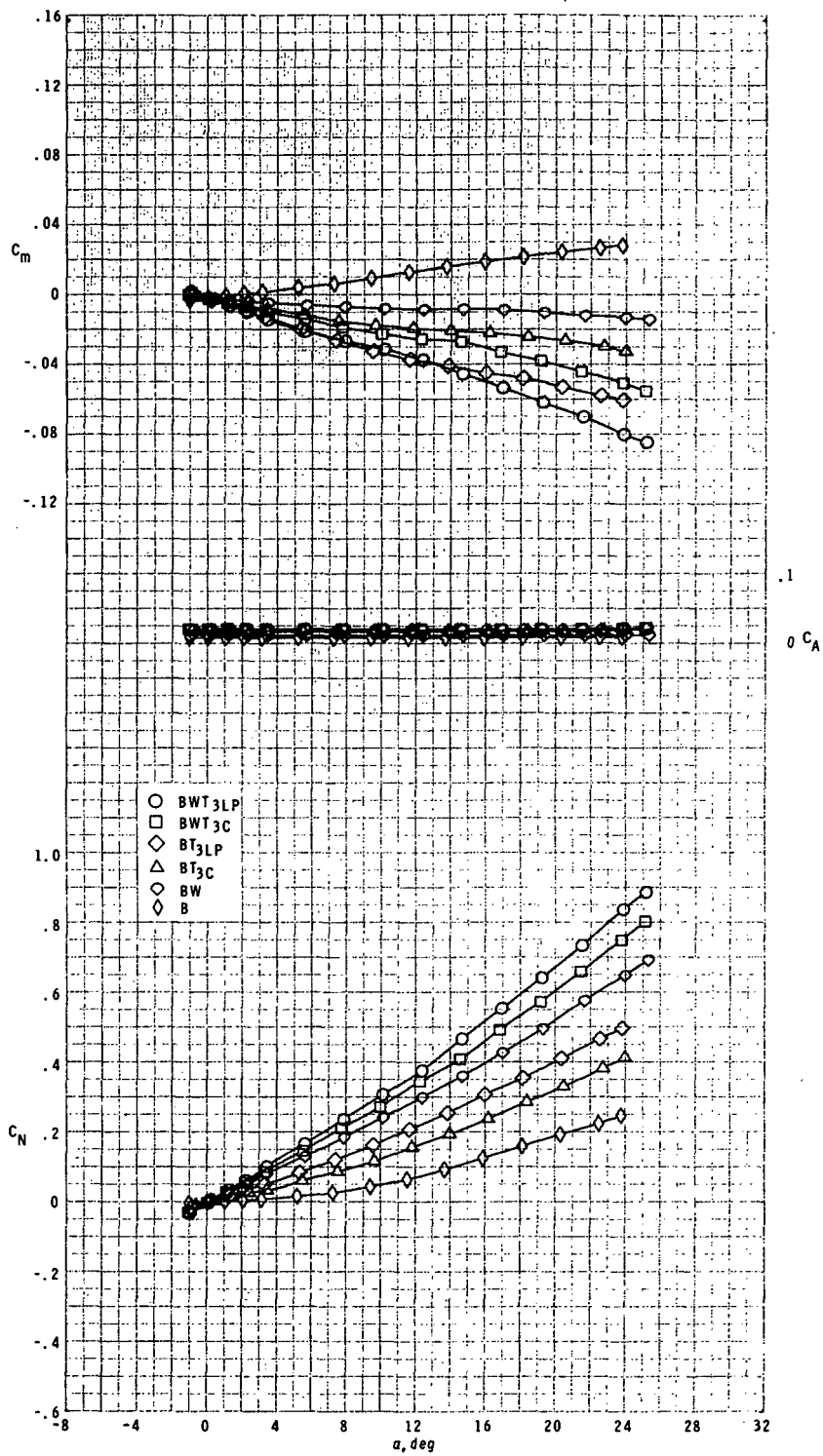
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Figure 4.- Continued.



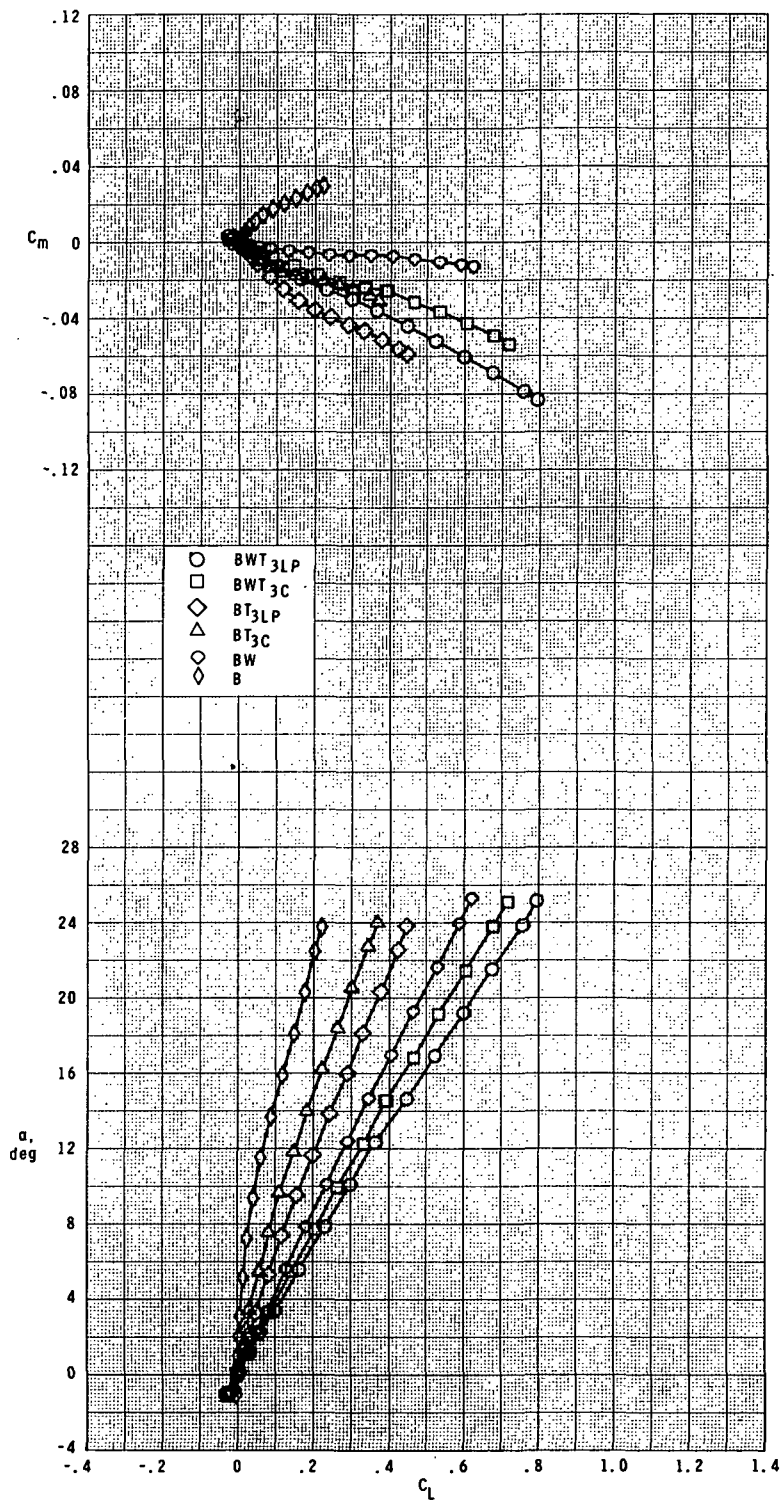
(b) Concluded.

Figure 4.- Continued.



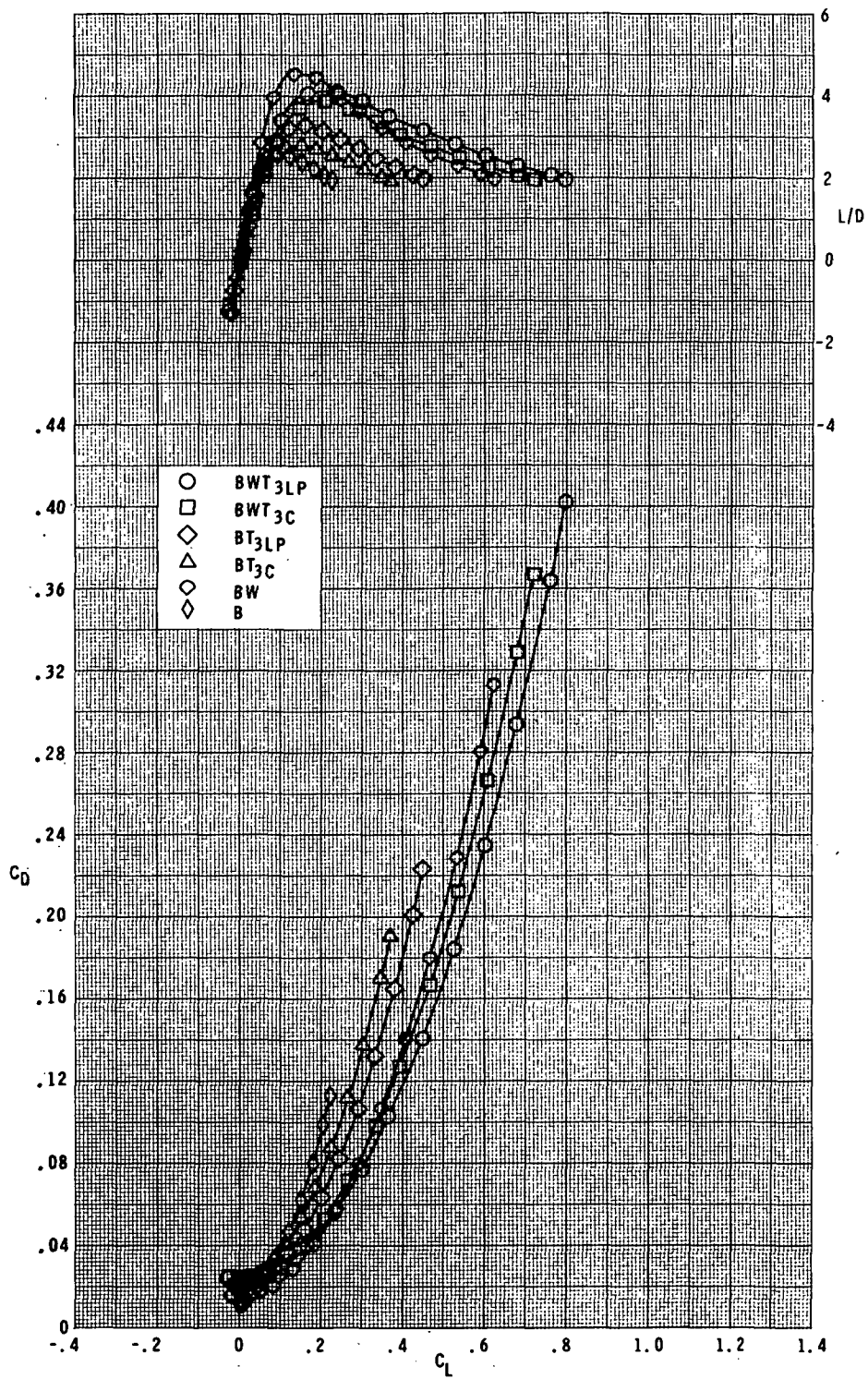
(c) $M = 2.36$.

Figure 4.- Continued.



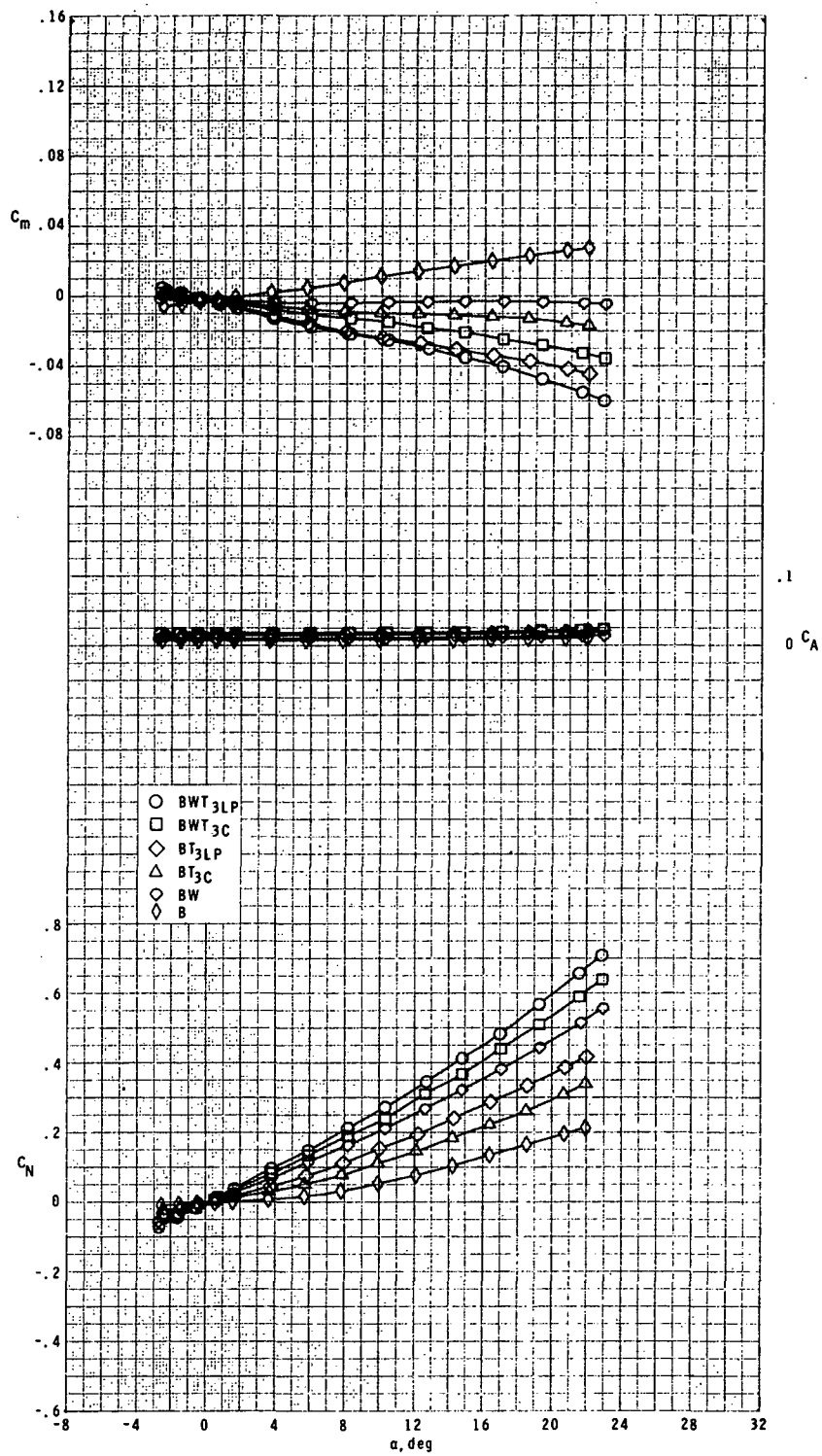
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Figure 4.- Continued.



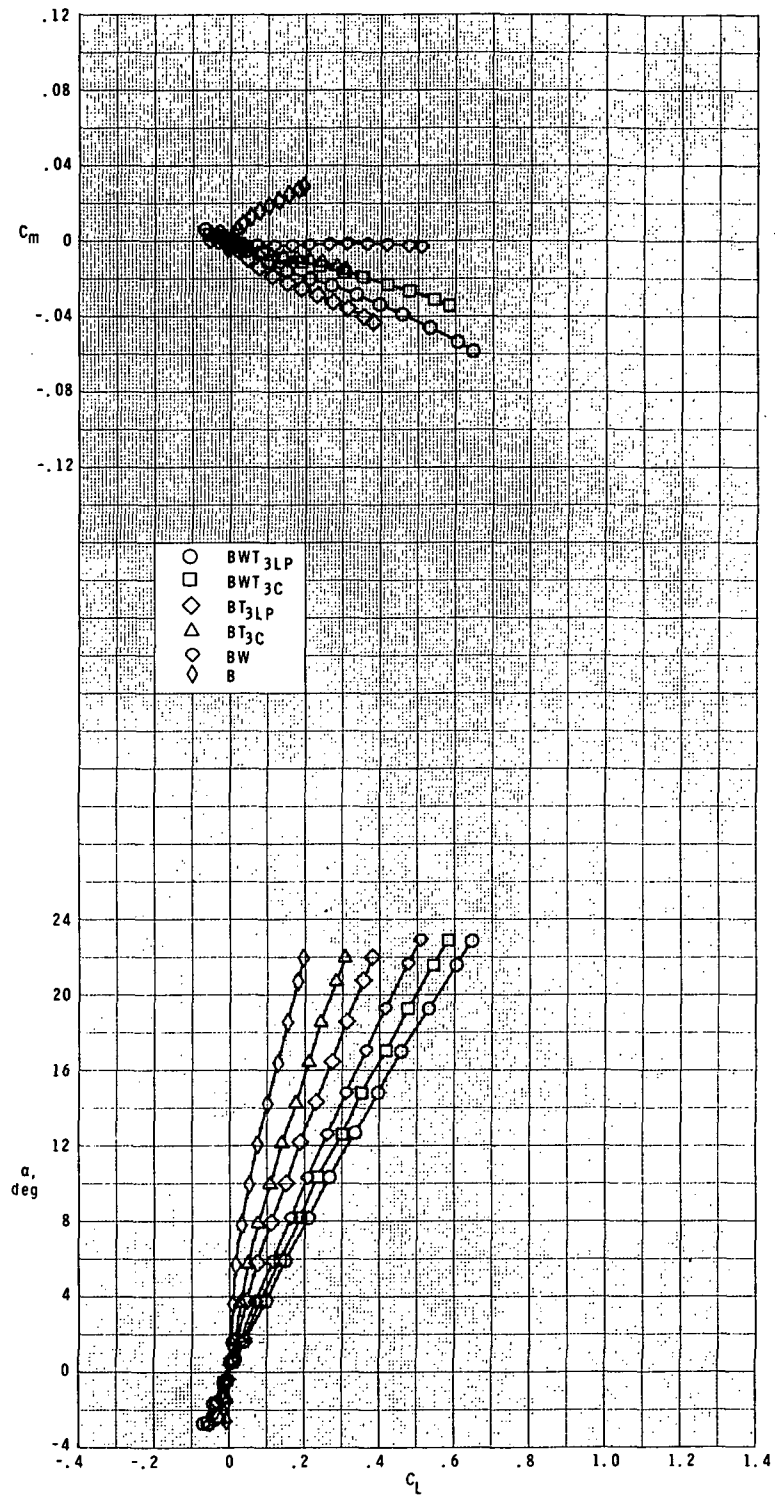
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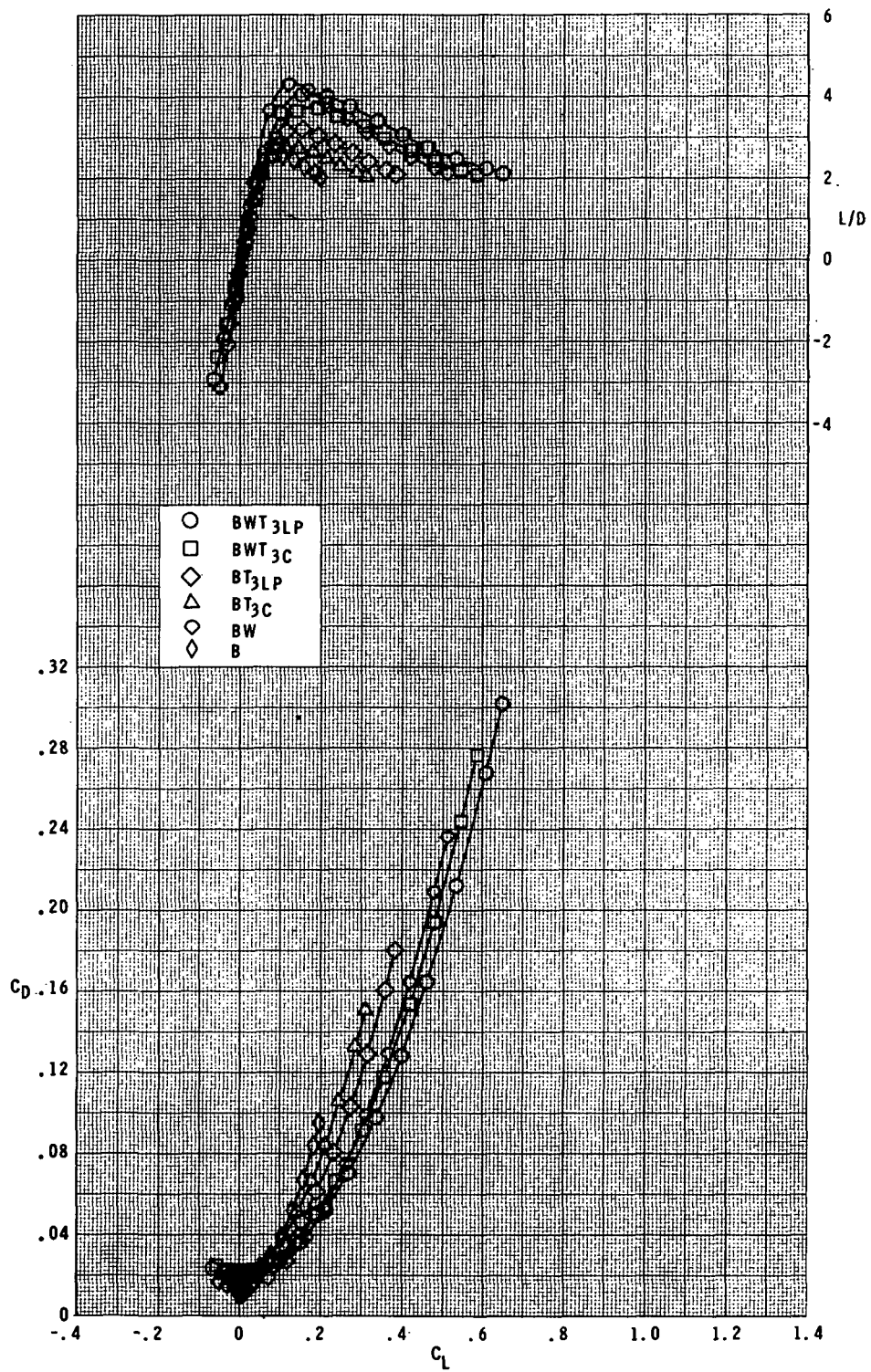
(d) $M = 2.86$.

Figure 4.- Continued.



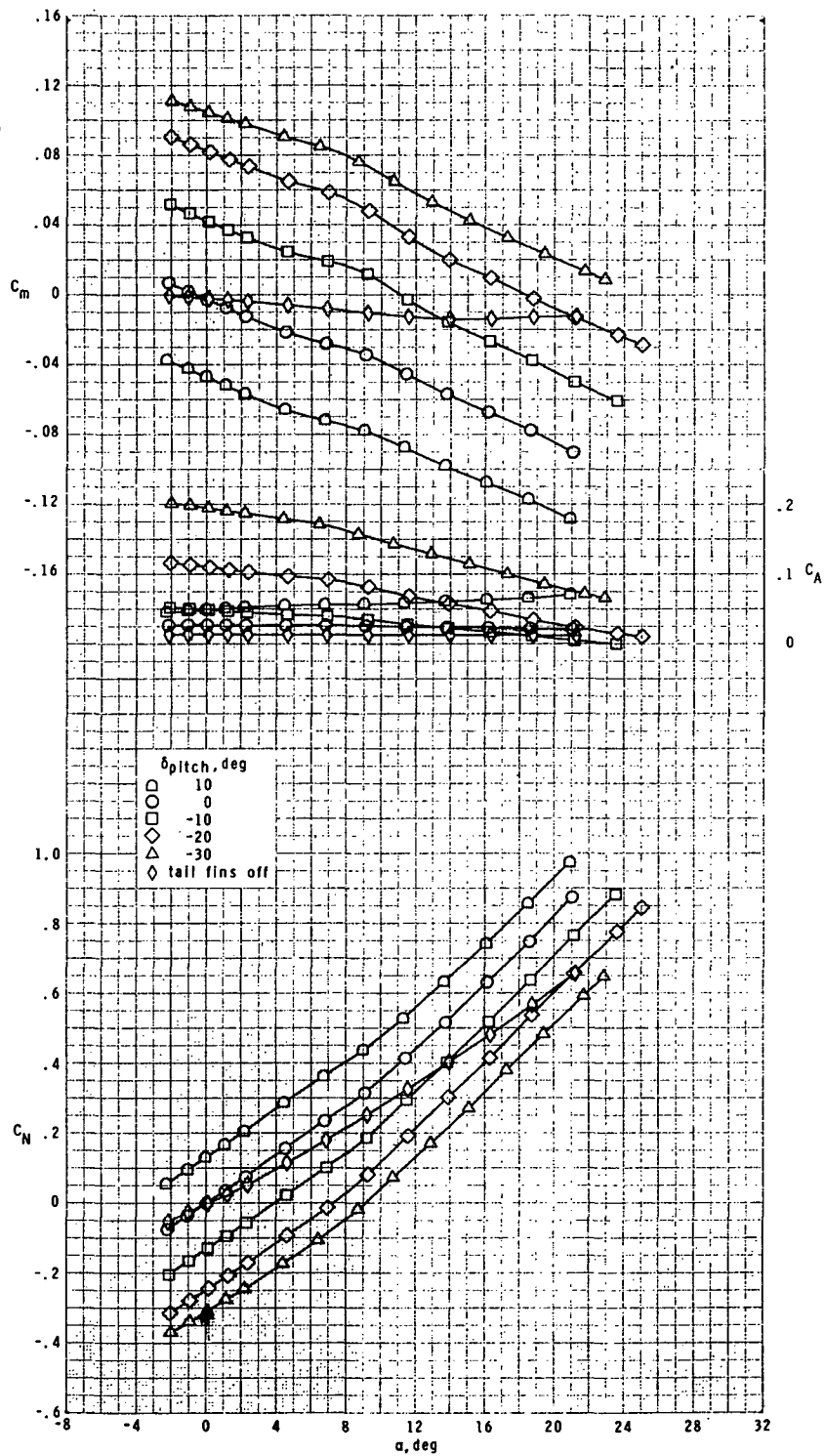
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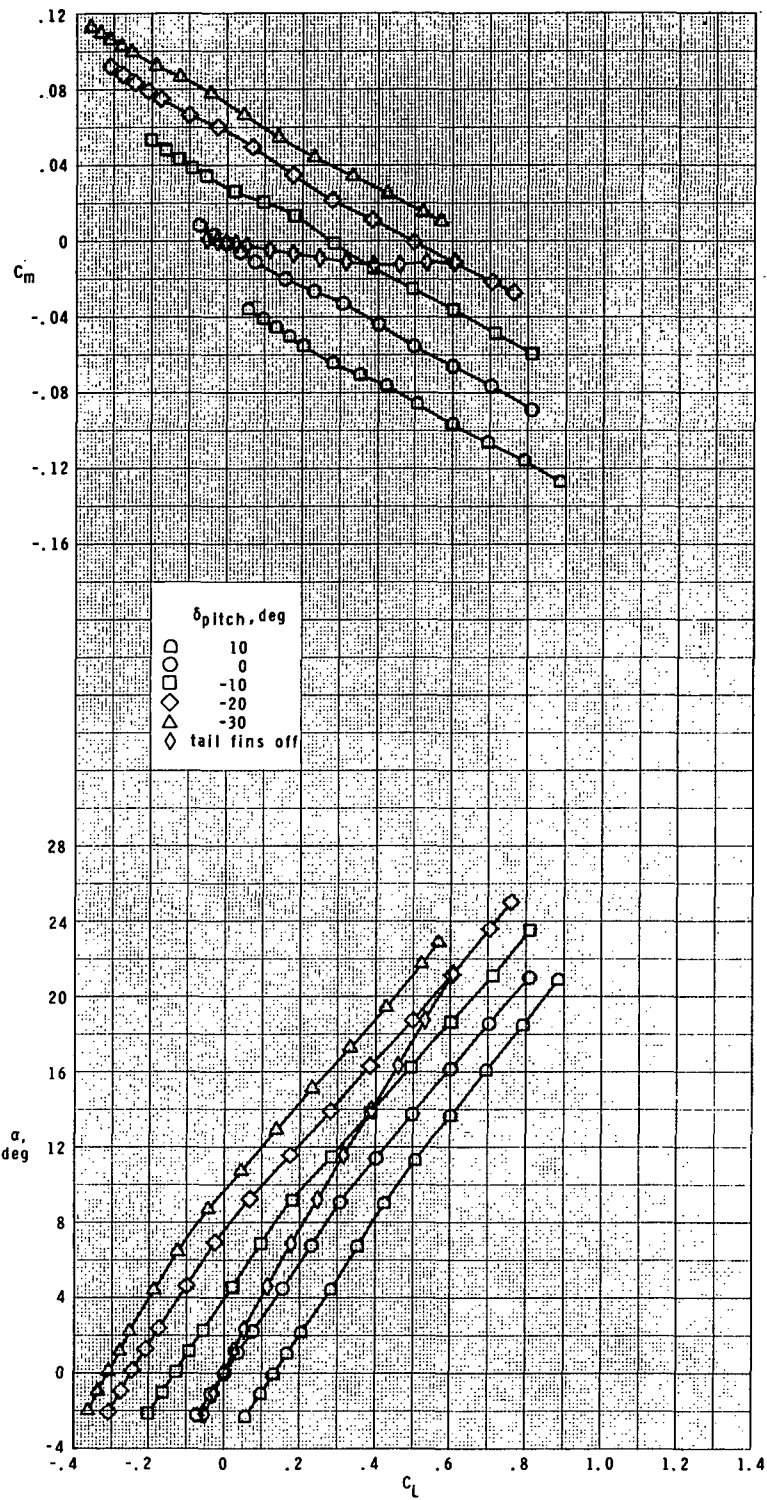
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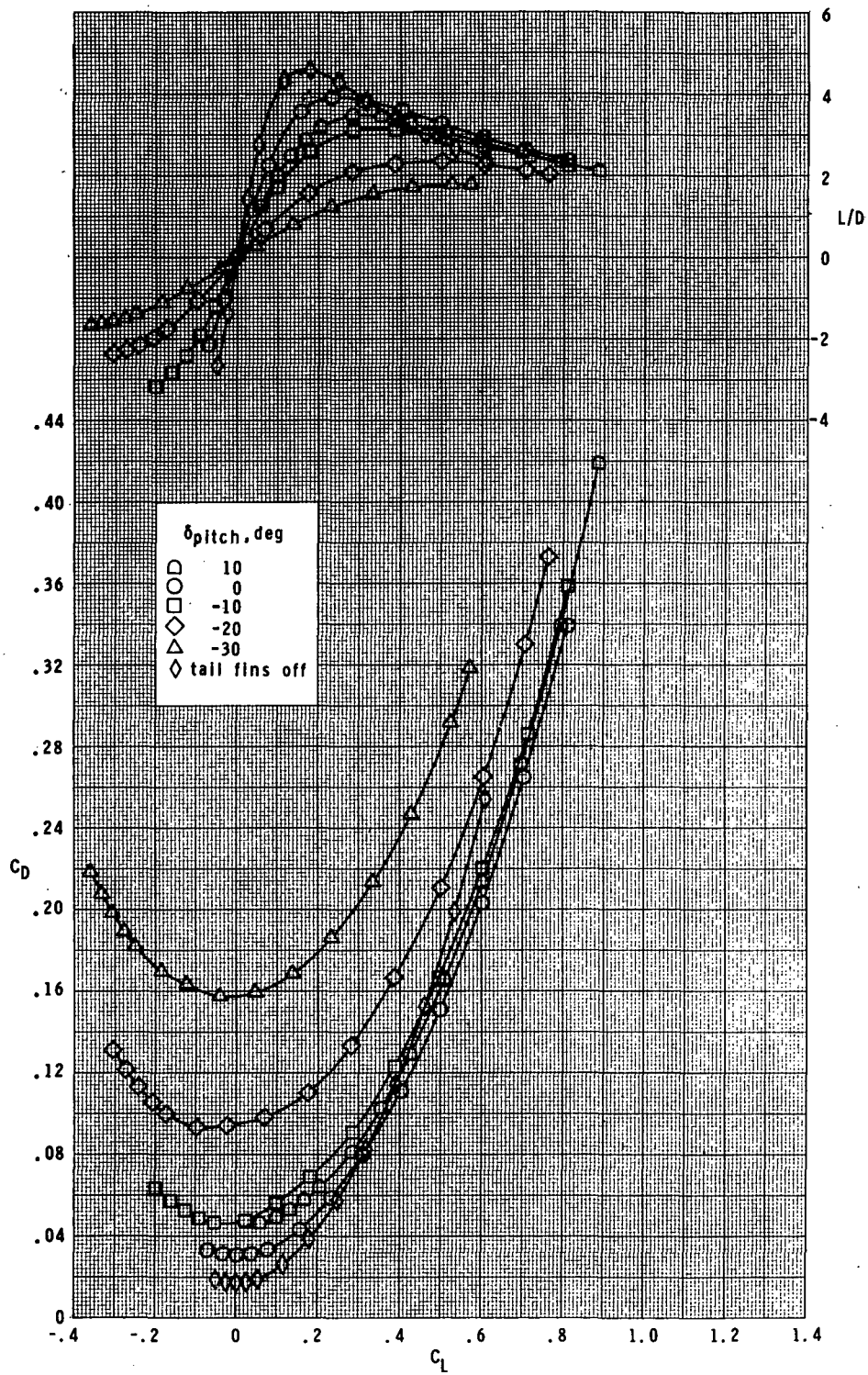
(a) $M = 1.70$.

Figure 5.- Pitch-control characteristics of low-profile tail configuration.



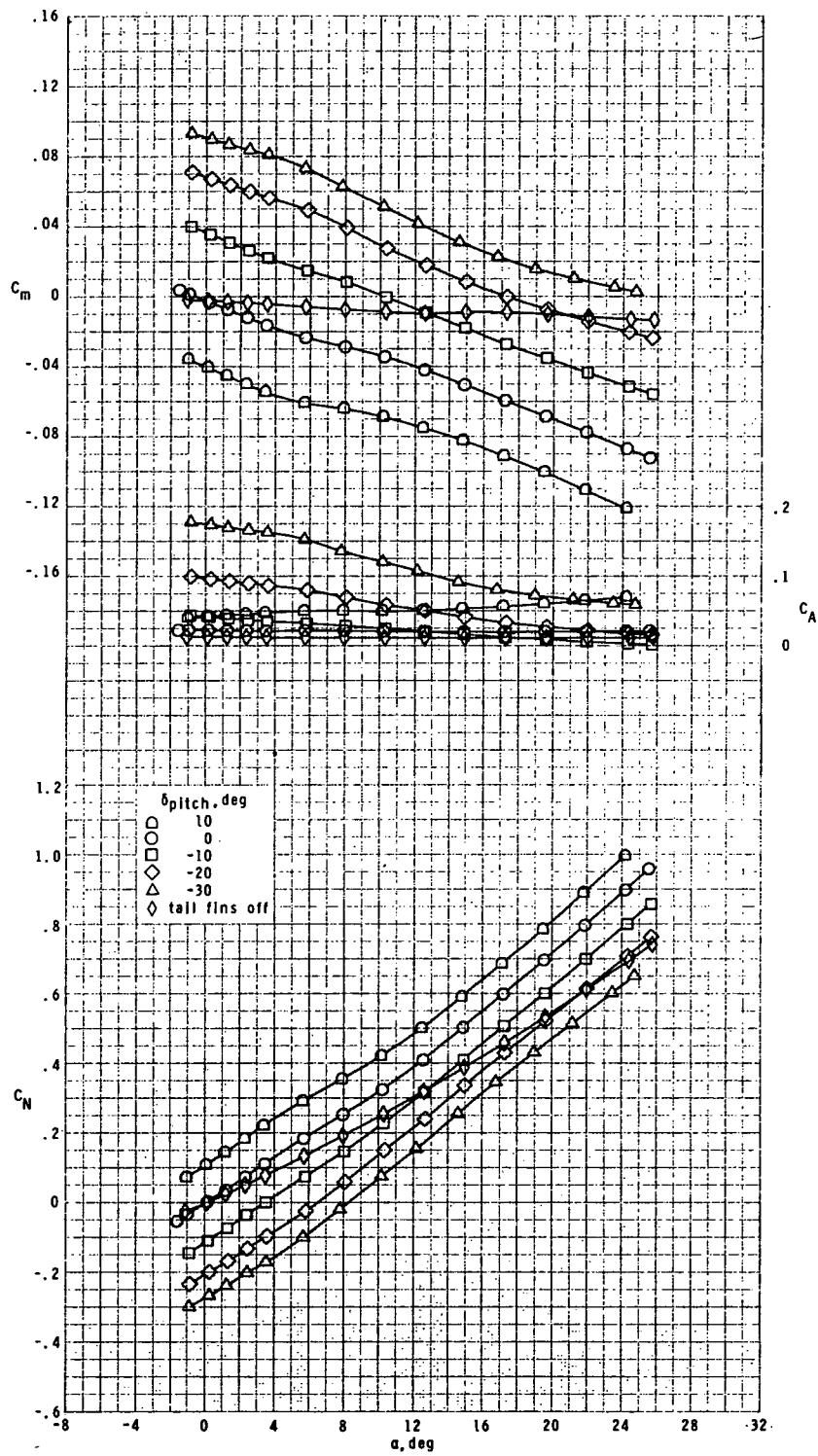
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Figure 5.- Continued.



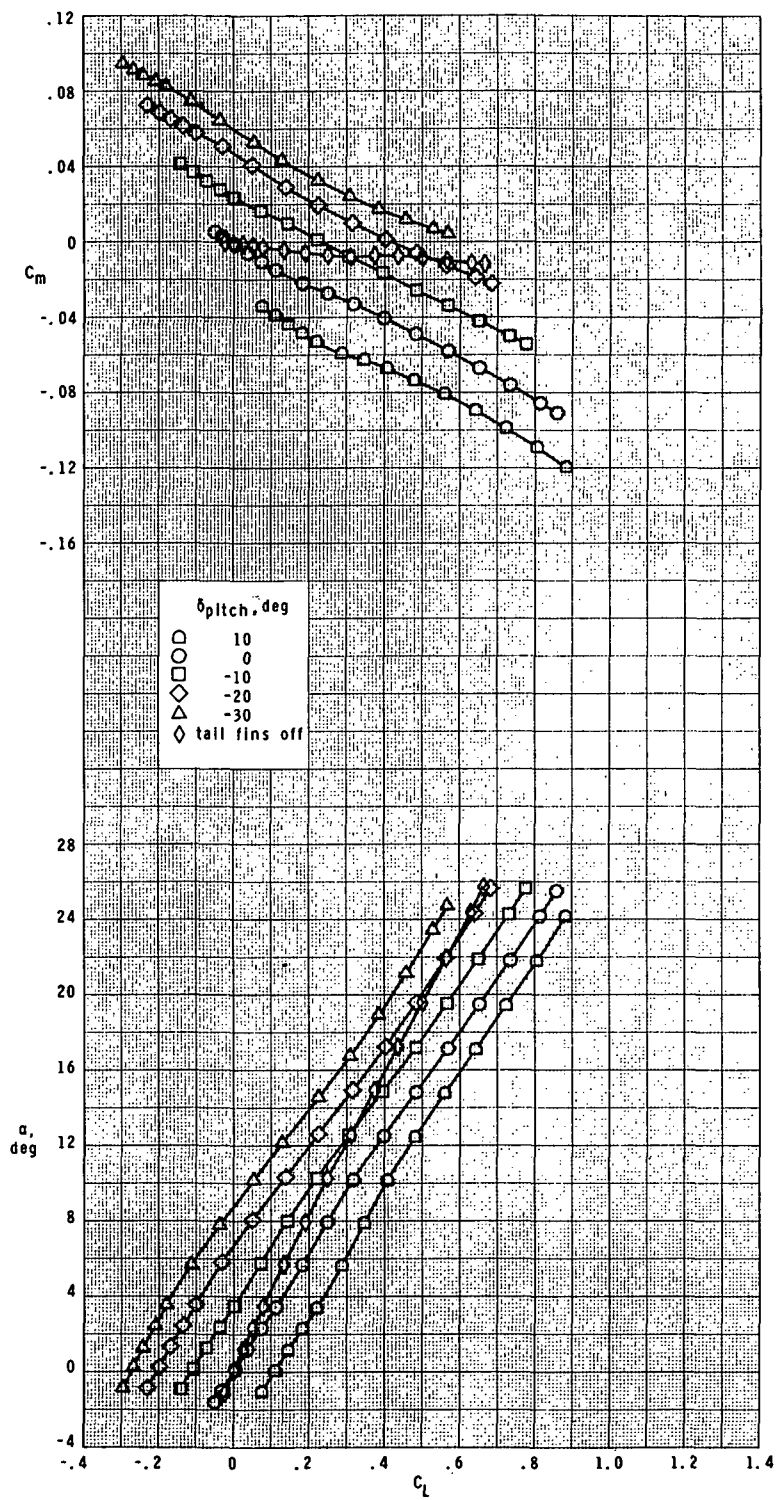
(a) Concluded.

Figure 5.- Continued.



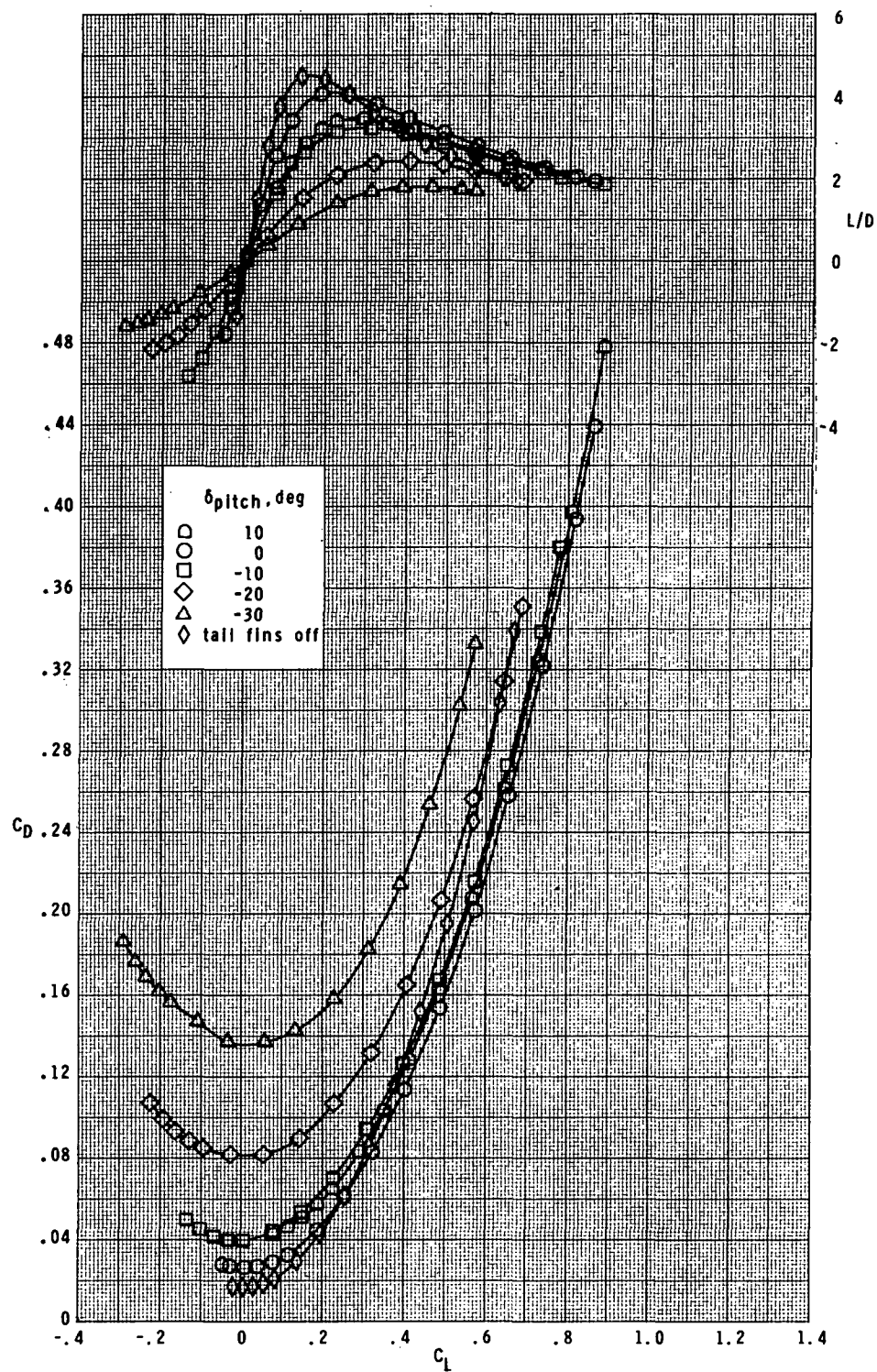
(b) $M = 2.16$.

Figure 5.- Continued.



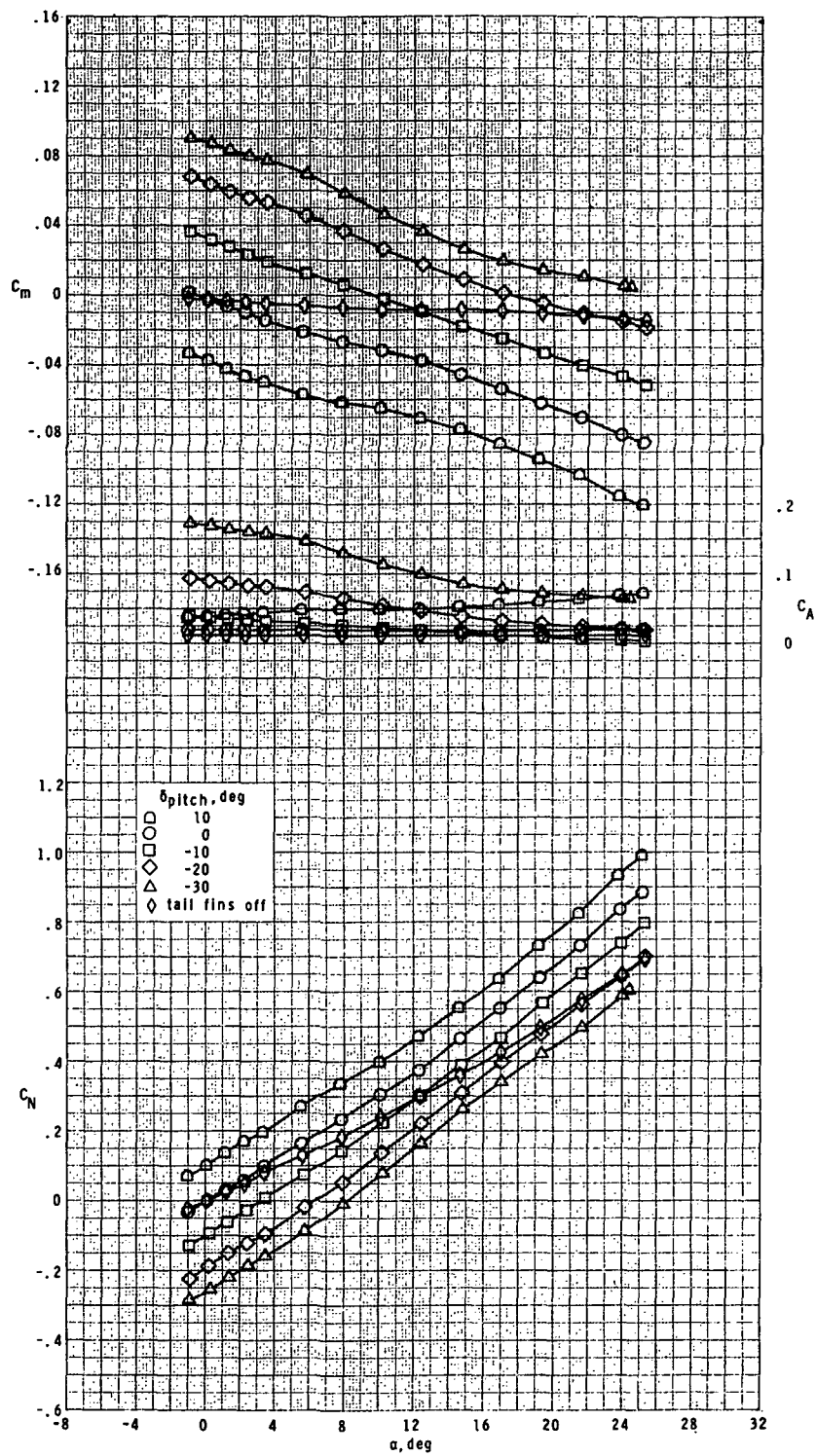
(b) Continued.

Figure 5.- Continued.



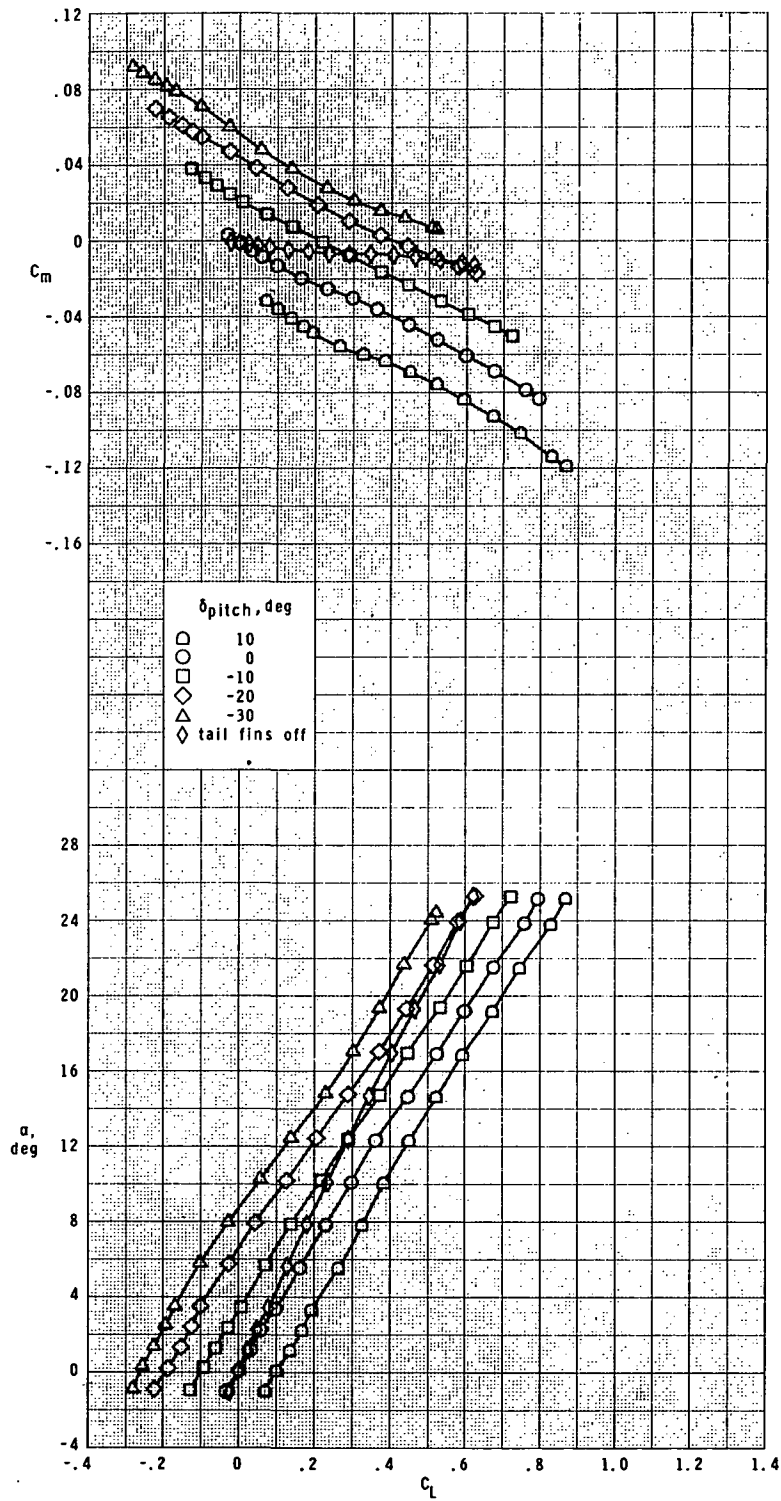
(b) Concluded.

Figure 5.- Continued.



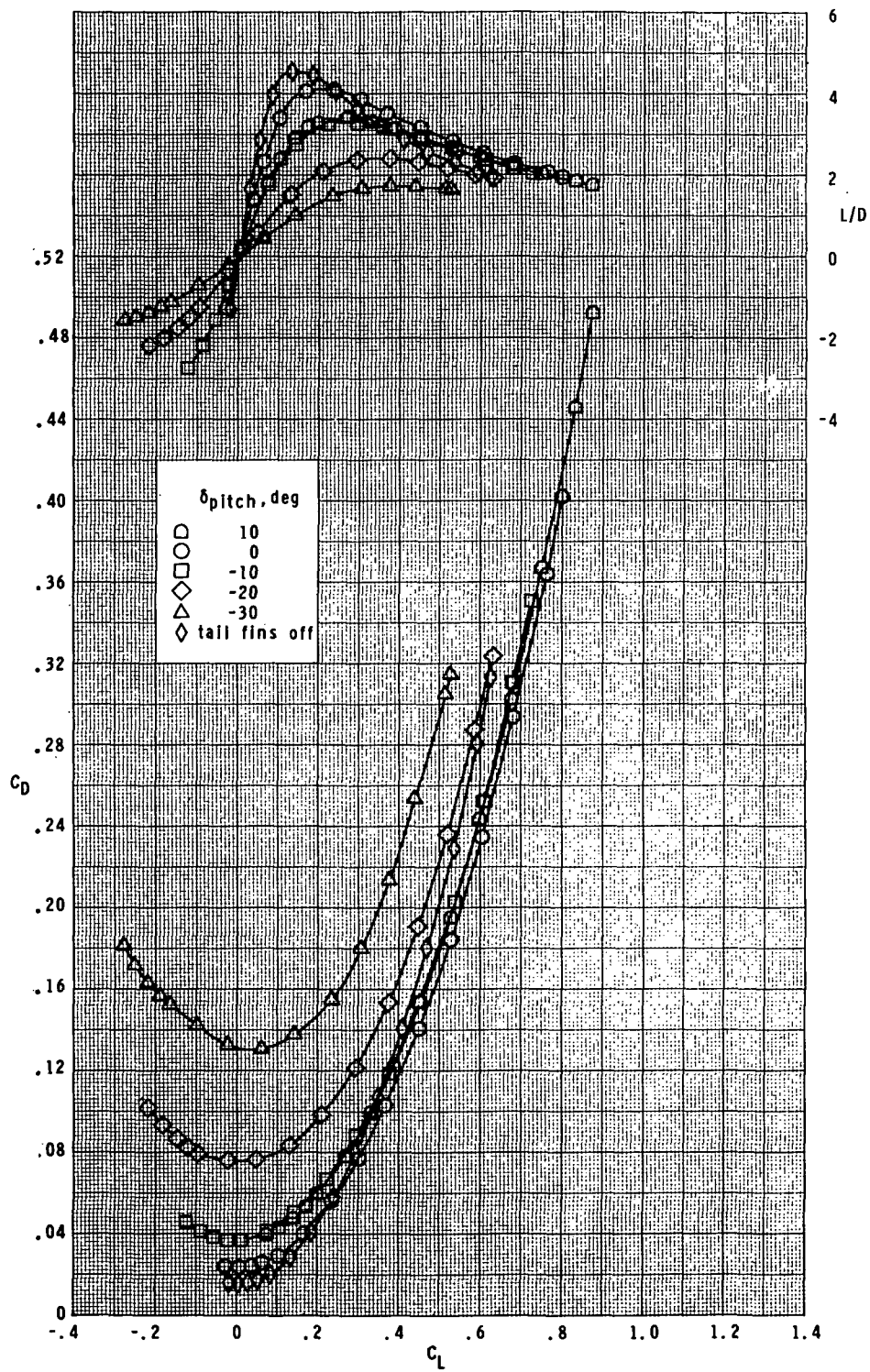
(c) $M = 2.36$.

Figure 5.- Continued.



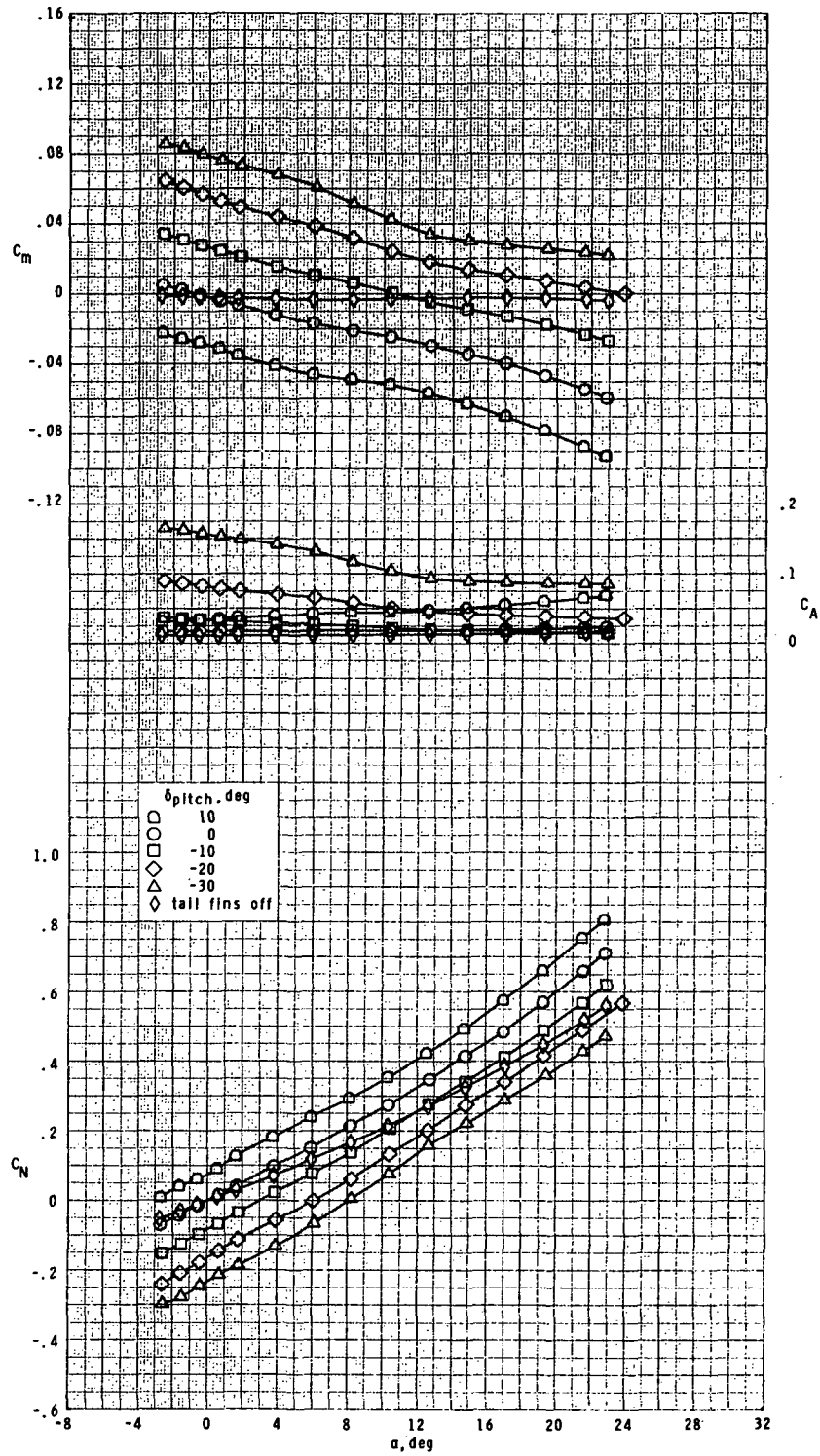
(c) Continued.

Figure 5.- Continued.



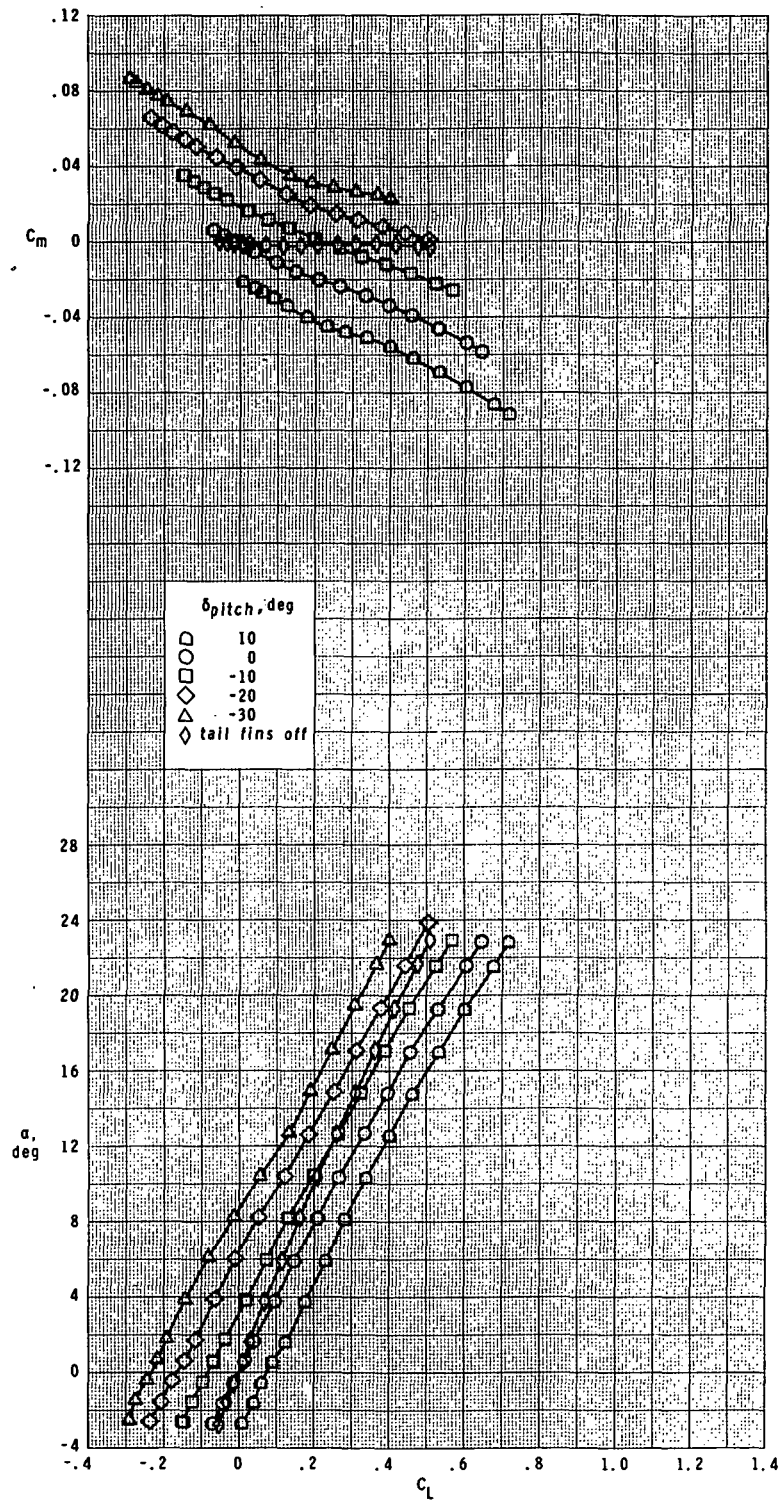
(c) Concluded.

Figure 5.- Continued.



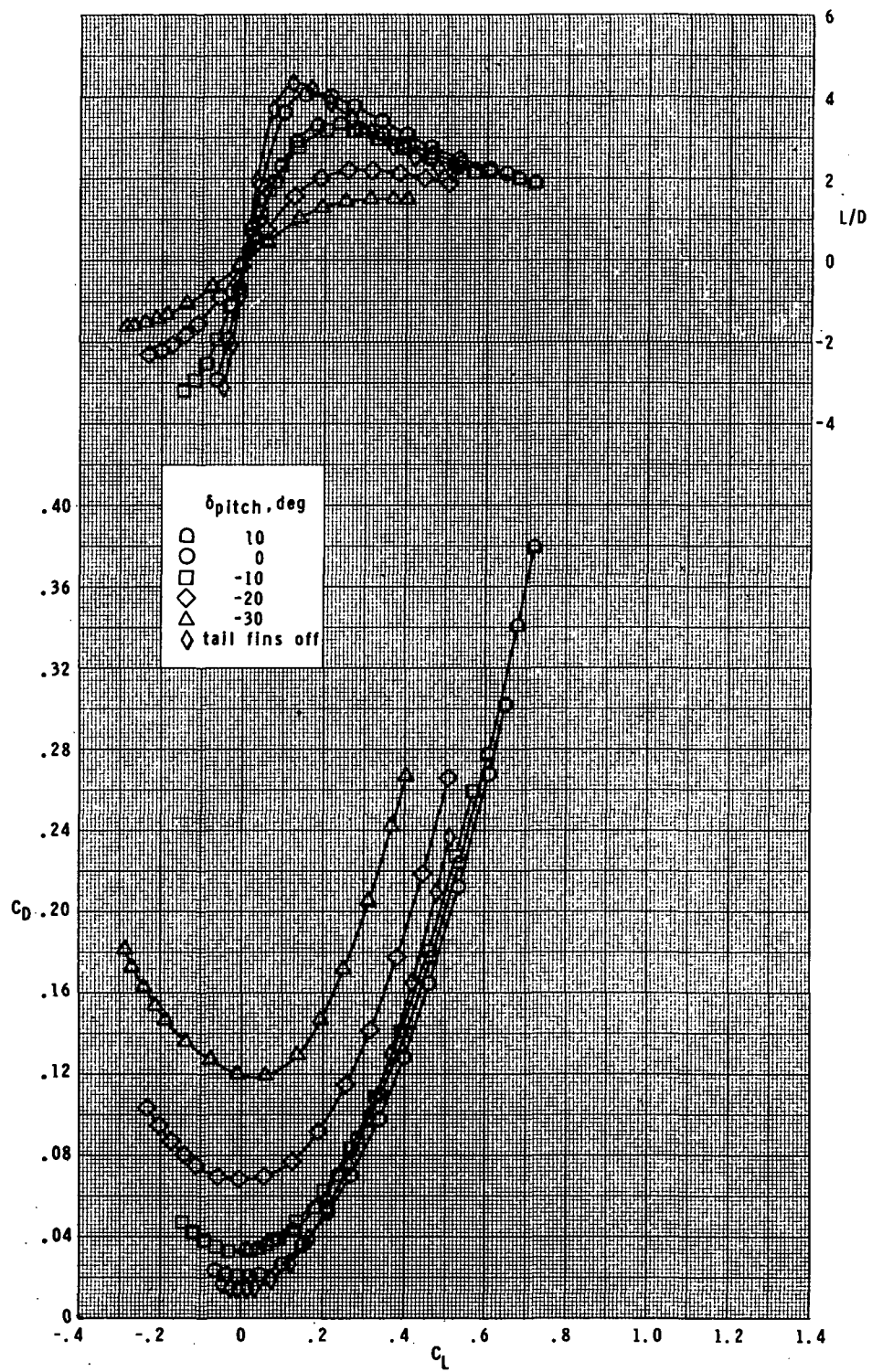
(d) $M = 2.86$.

Figure 5.- Continued.



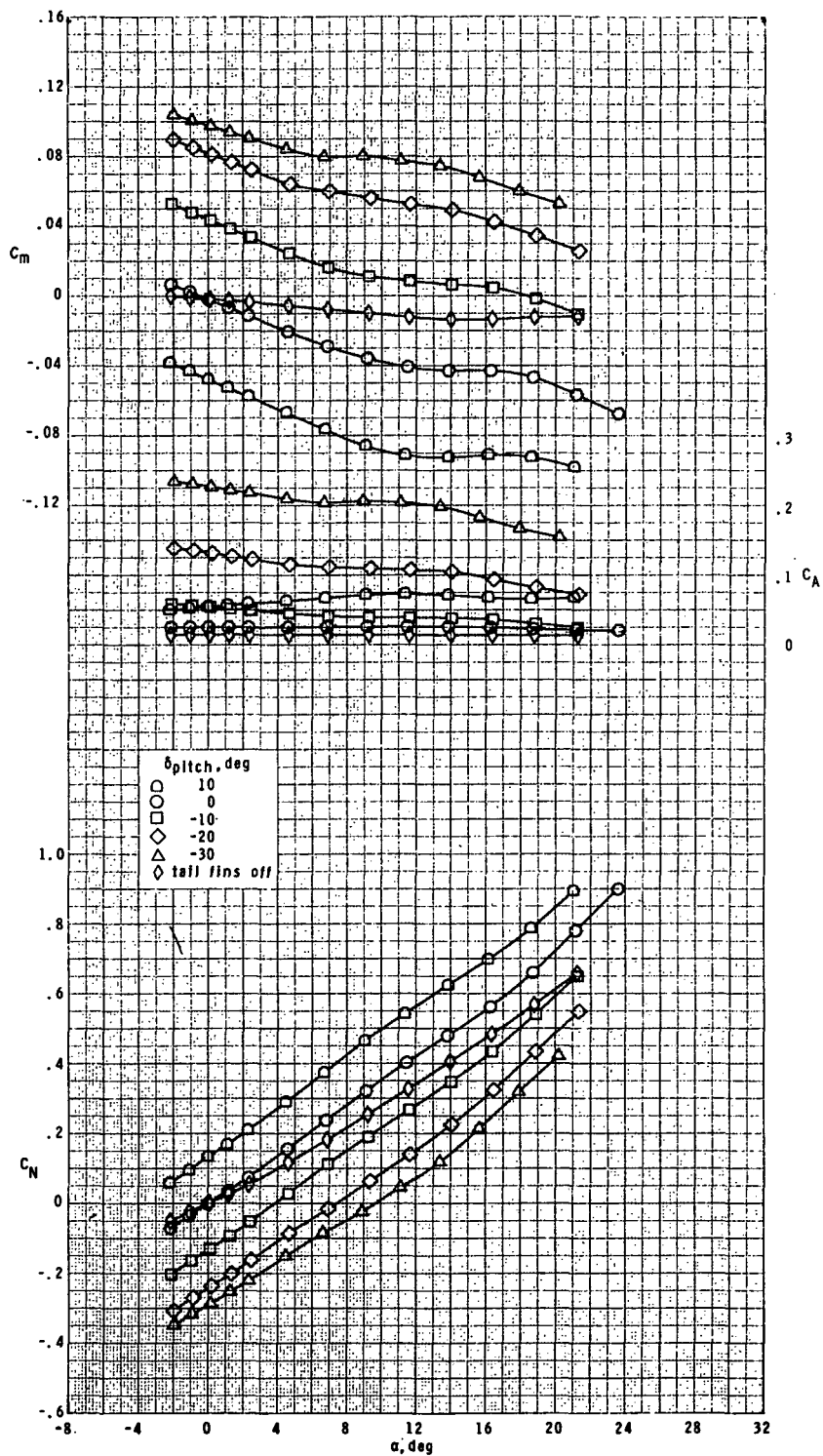
(d) Continued.

Figure 5.- Continued.



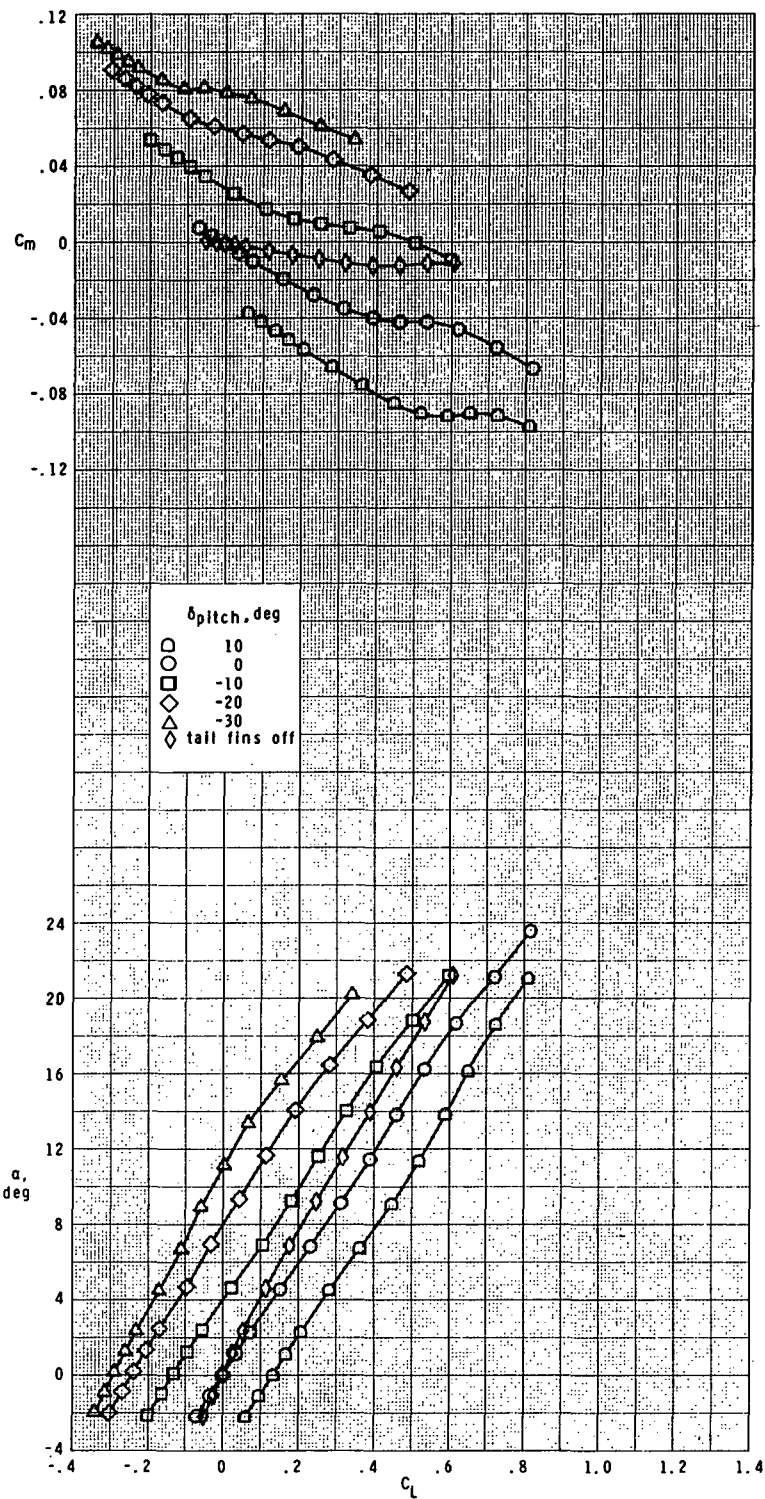
(d) Concluded.

Figure 5.- Concluded.



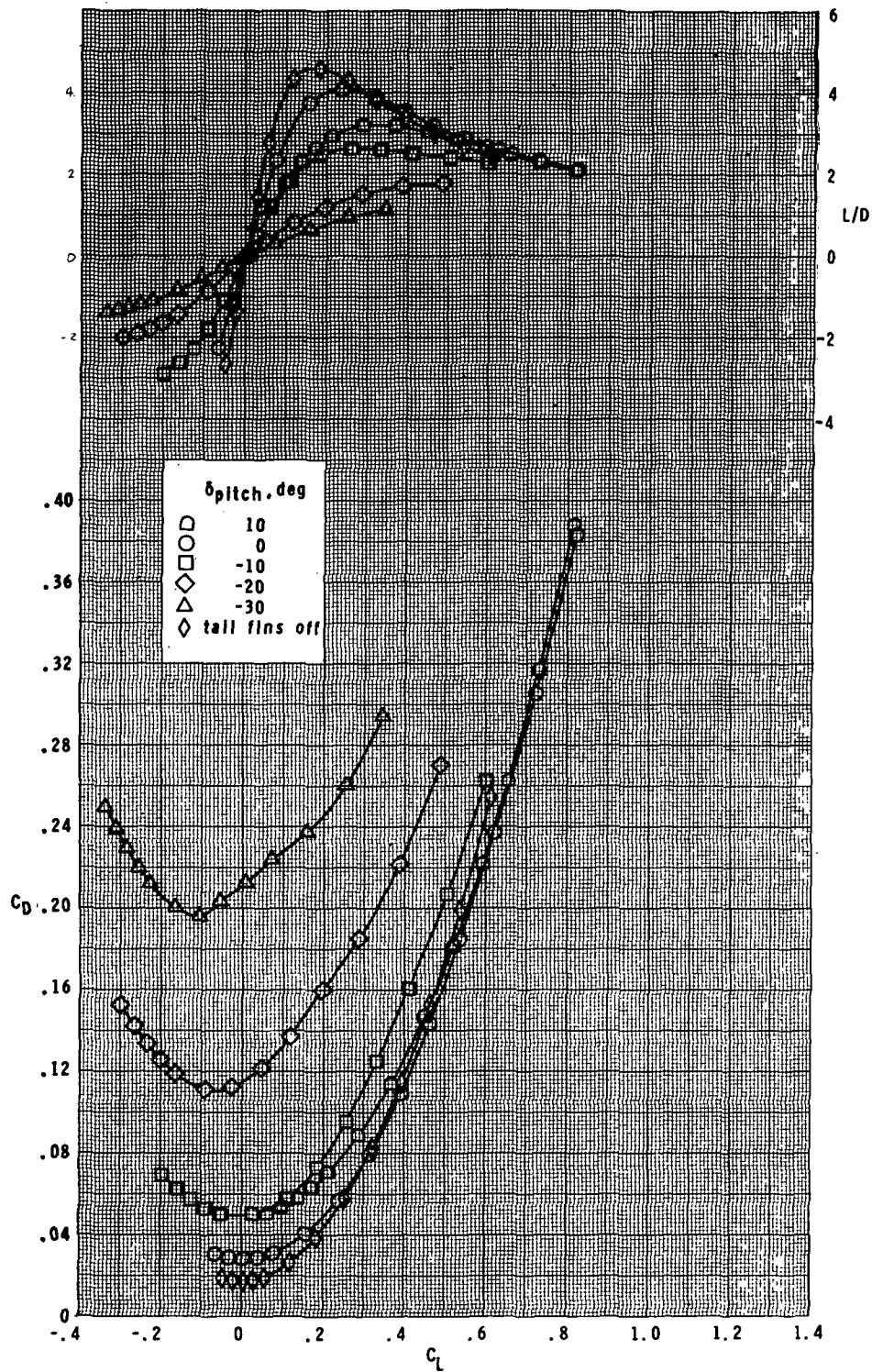
(a) $M = 1.70$.

Figure 6.- Pitch-control characteristics of conventional-cruciform tail configuration.



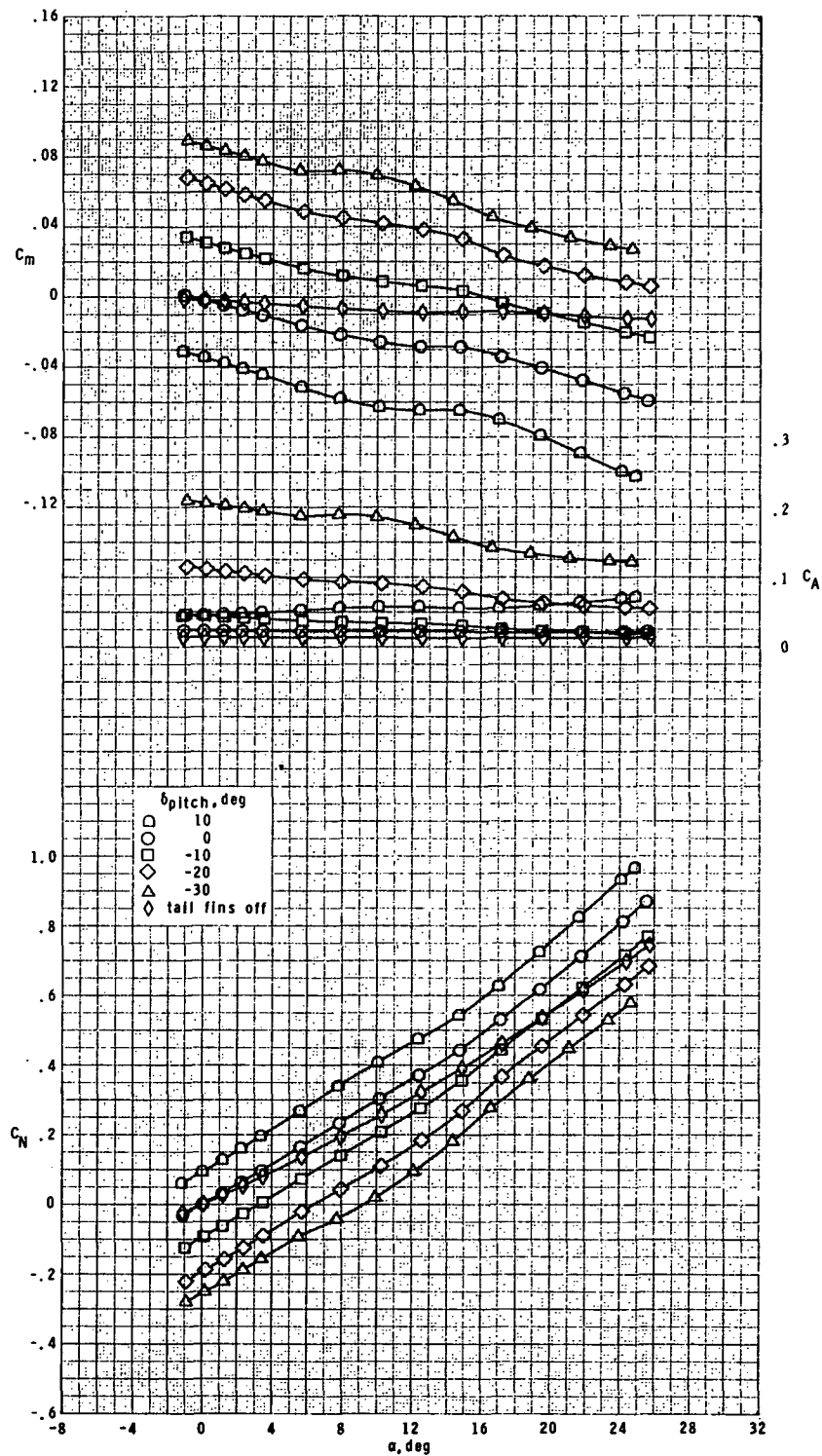
(a) Continued.

Figure 6.- Continued.



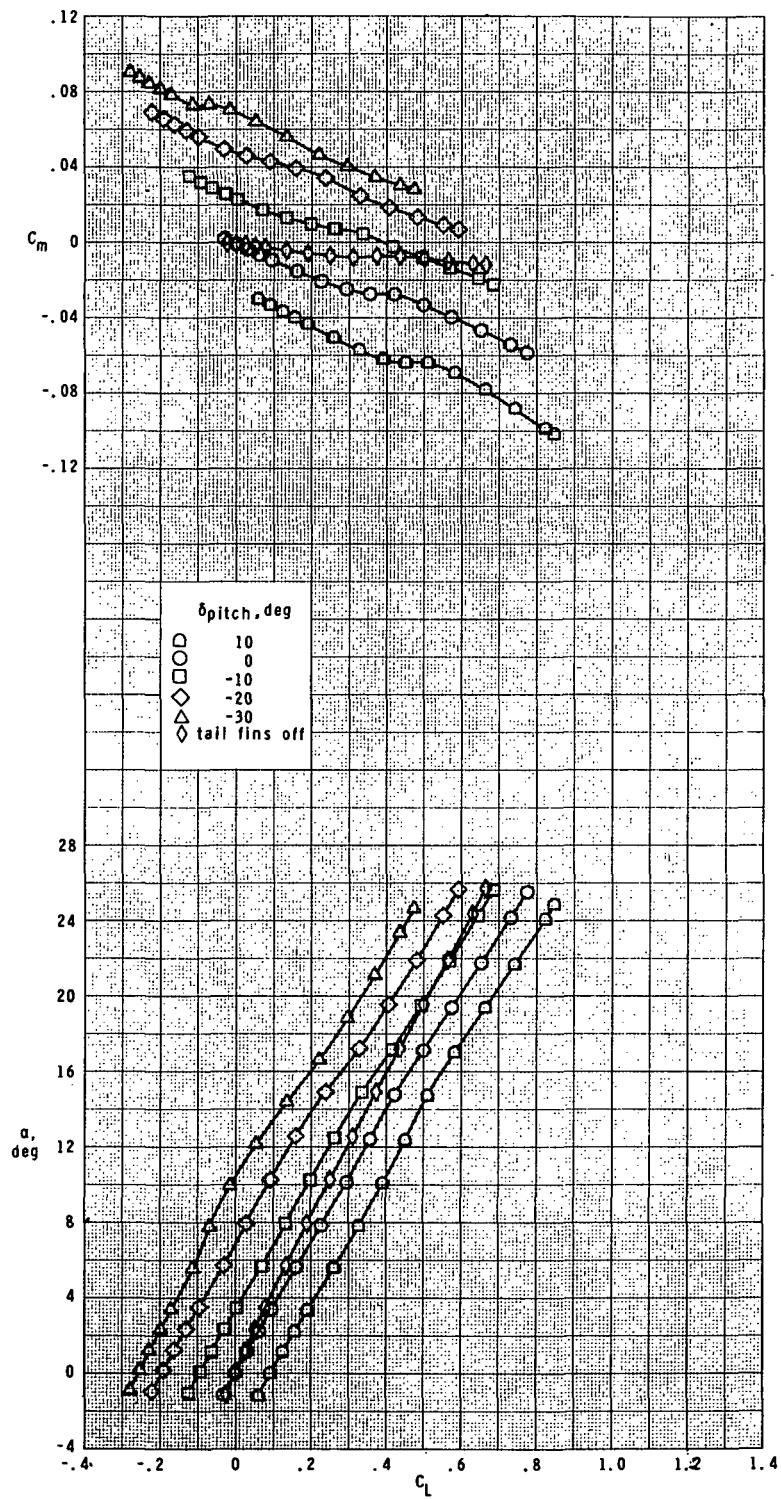
(a) Concluded.

Figure 6.- Continued.



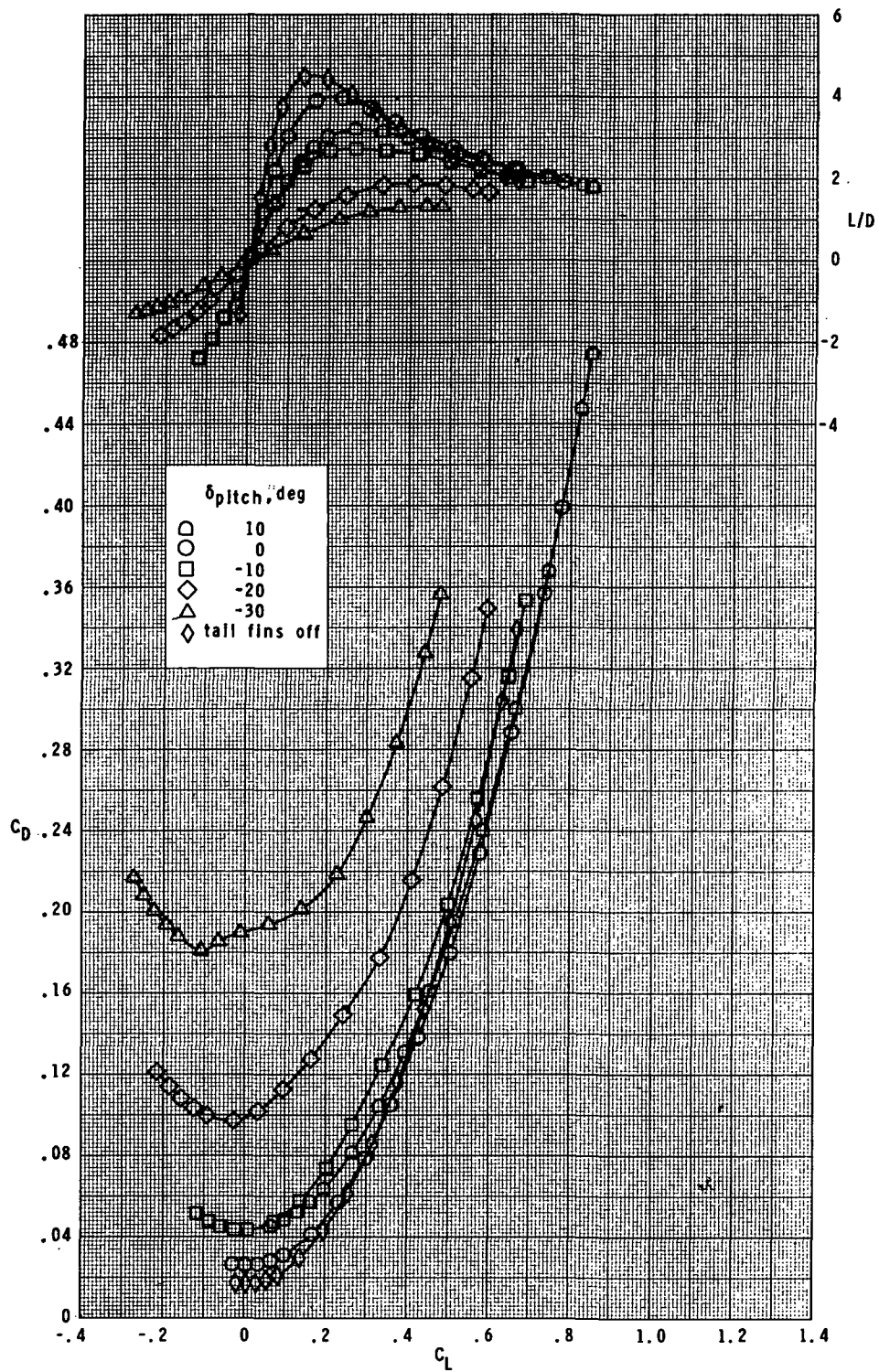
(b) $M = 2.16$.

Figure 6.- Continued.



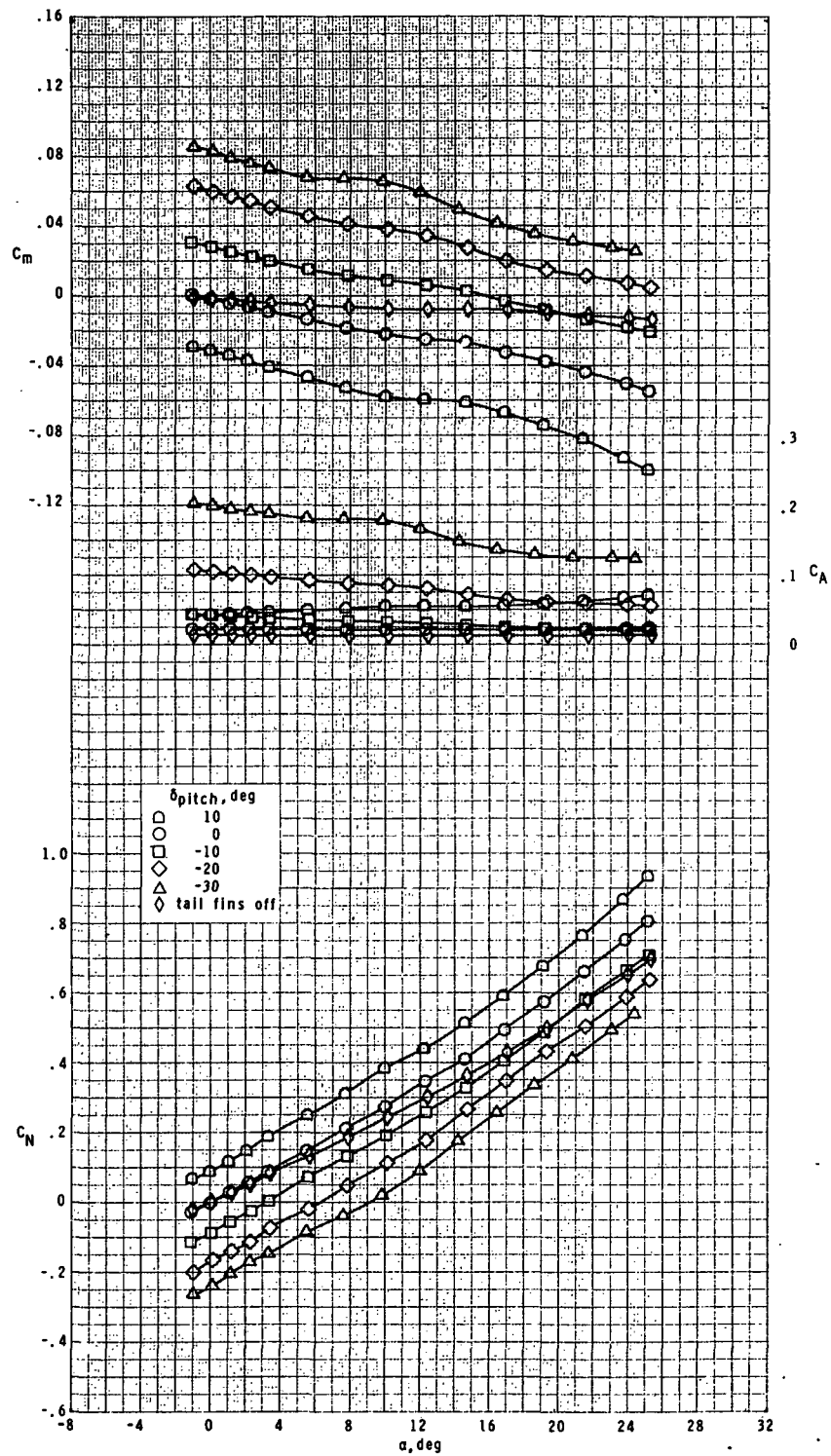
(b) Continued.

Figure 6.- Continued.



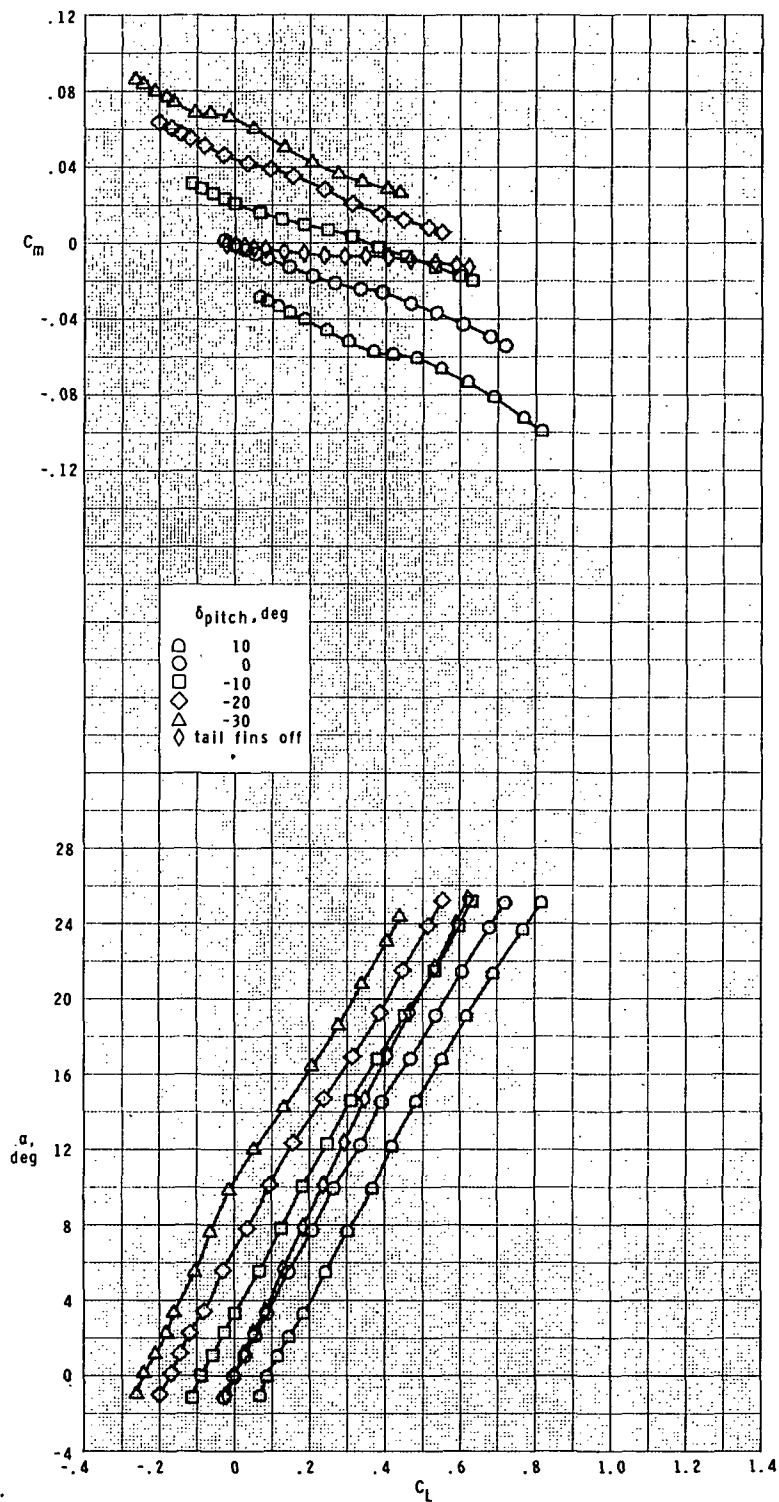
(b) Concluded.

Figure 6.- Continued.



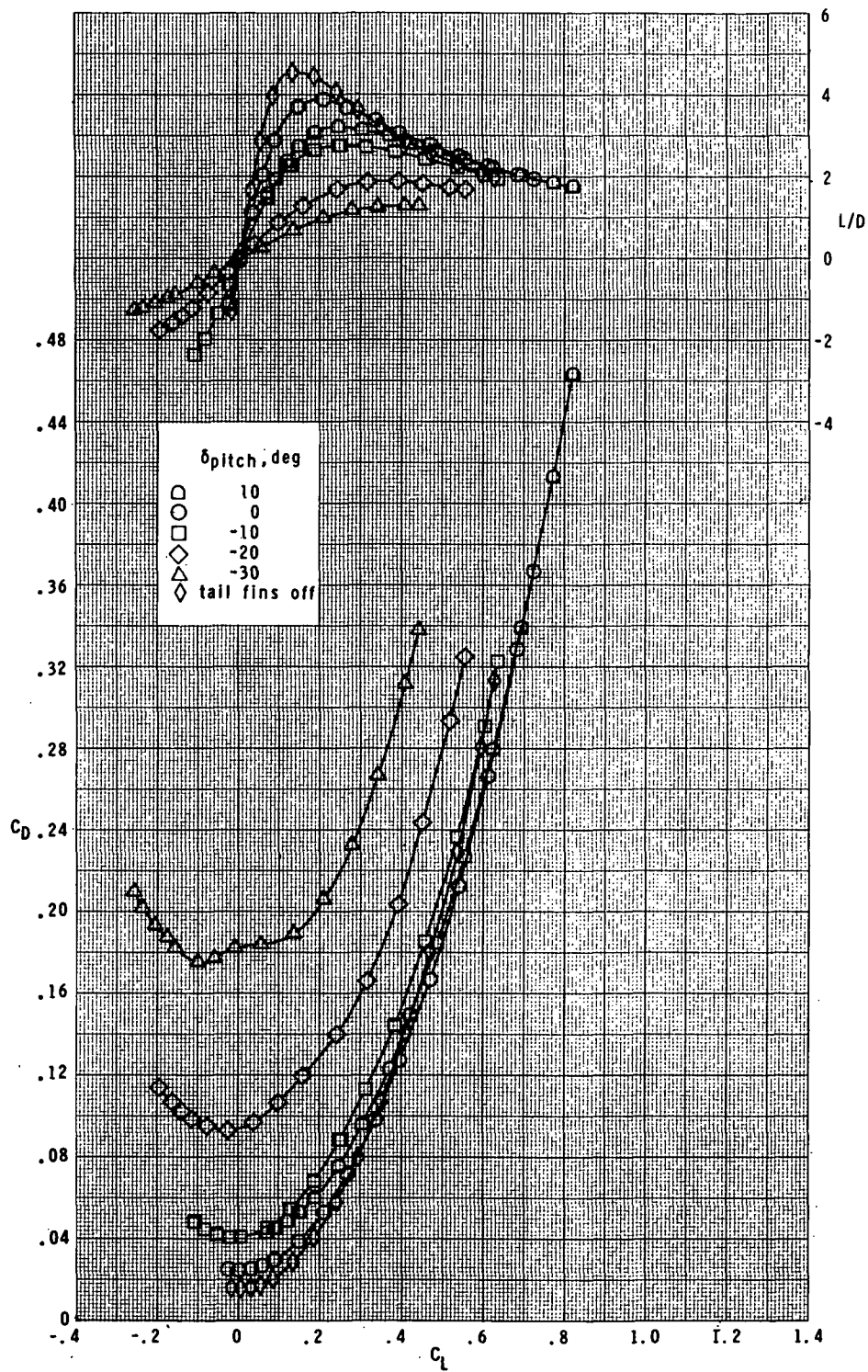
(c) $M = 2.36$.

Figure 6.- Continued.



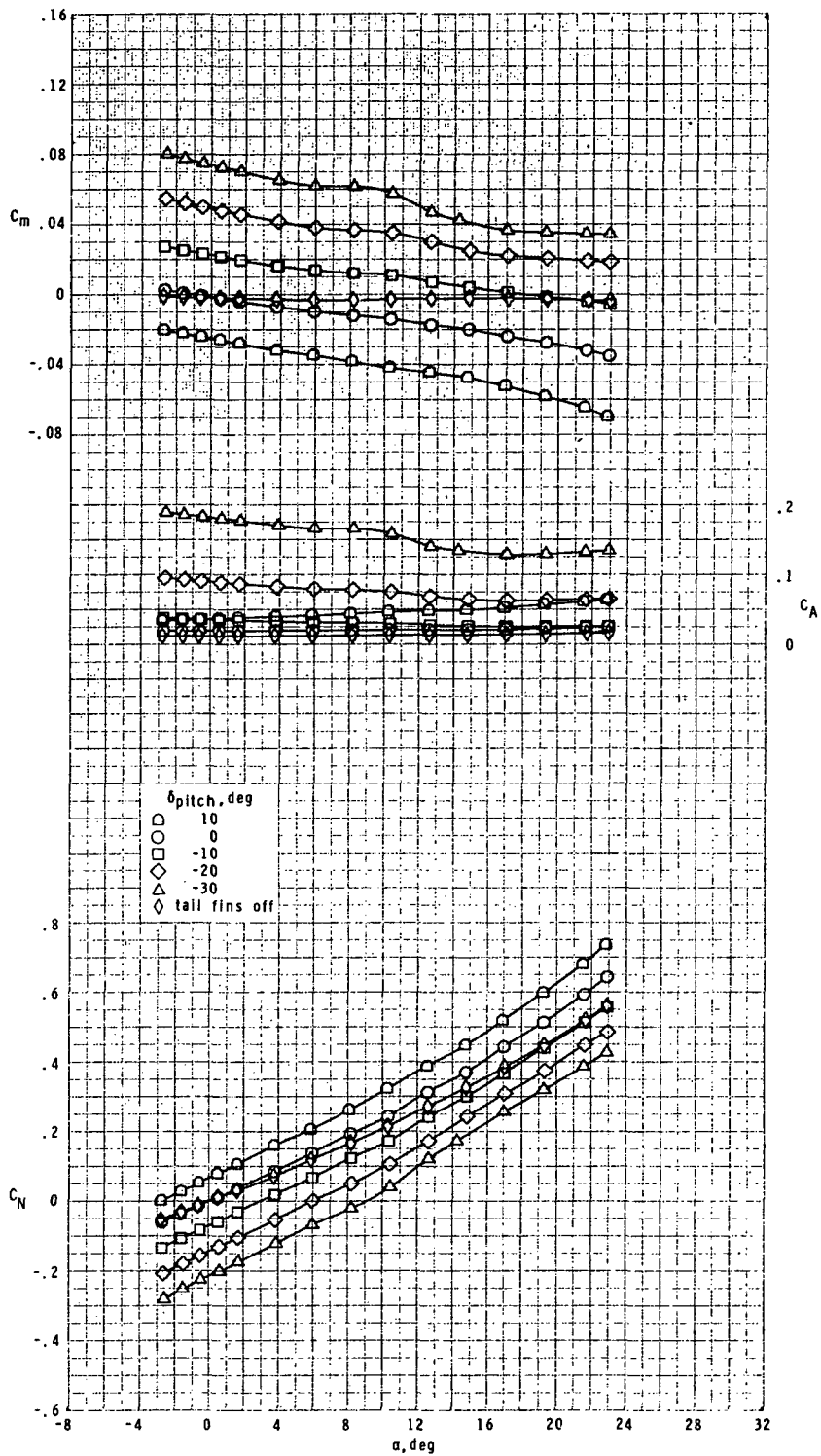
(c) Continued.

Figure 6.- Continued.



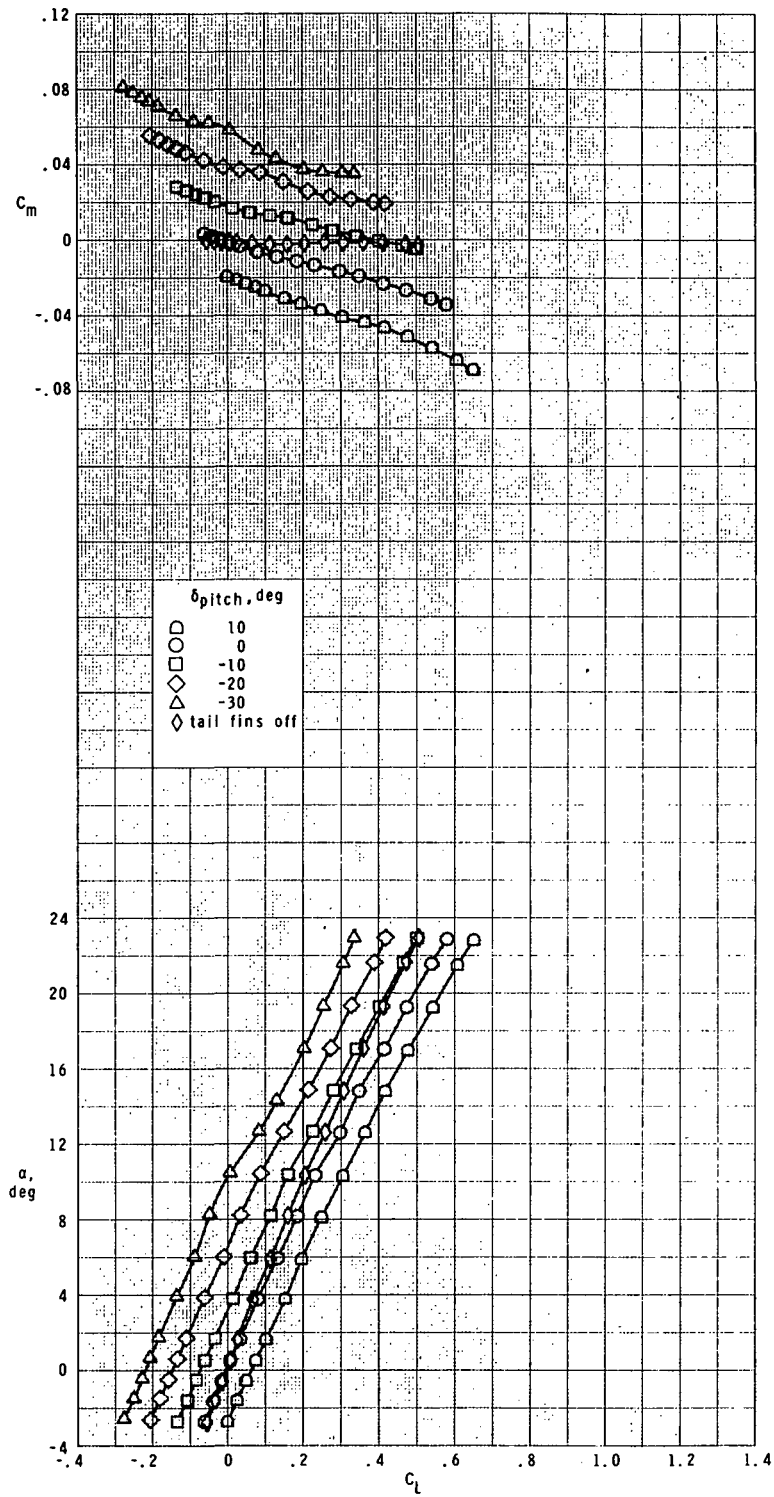
(c) Concluded.

Figure 6.- Continued.



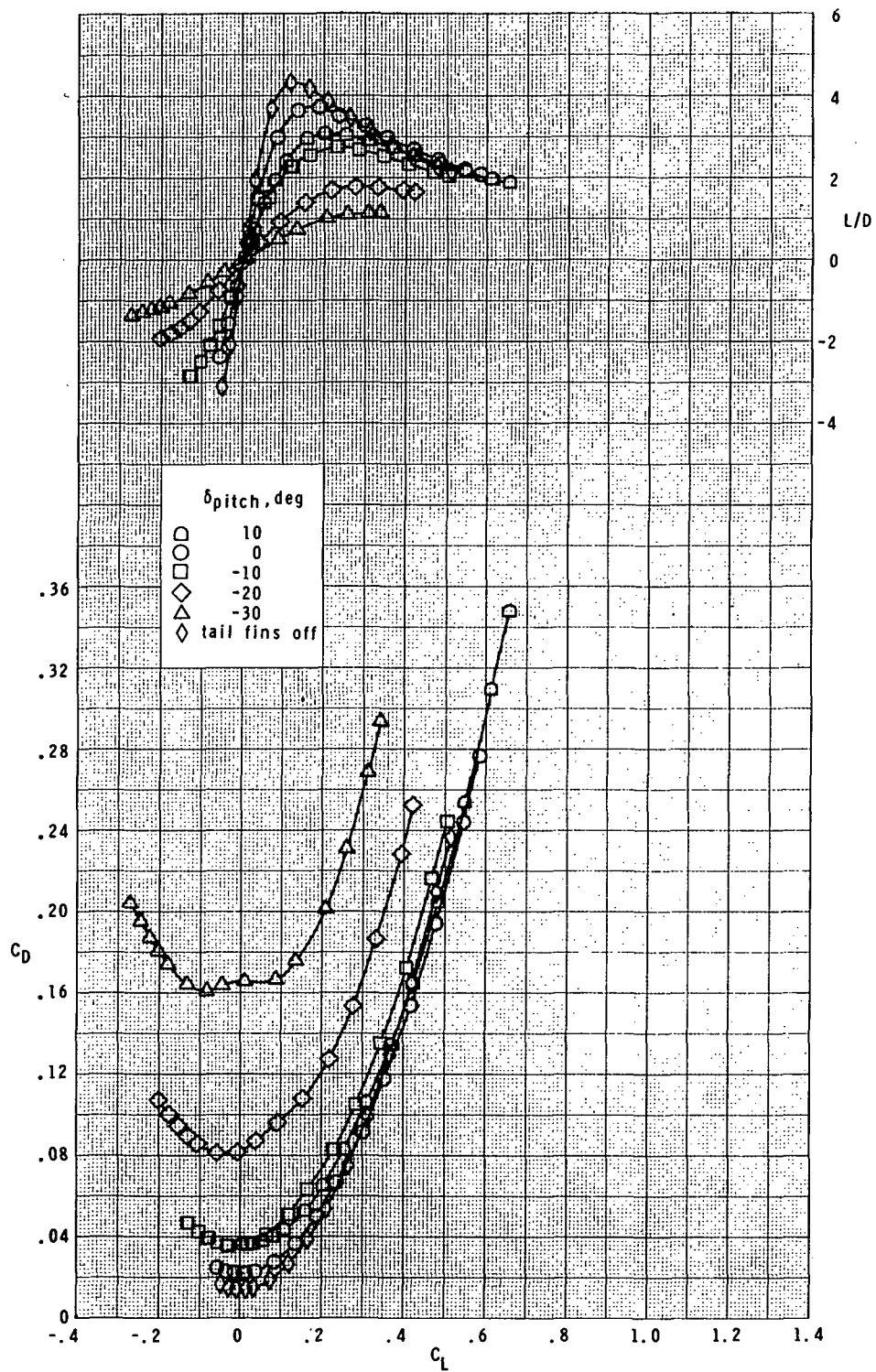
(d) $M = 2.86$.

Figure 6.- Continued.



(d) Continued.

Figure 6.- Continued.



(d) Concluded.

Figure 6.- Concluded.

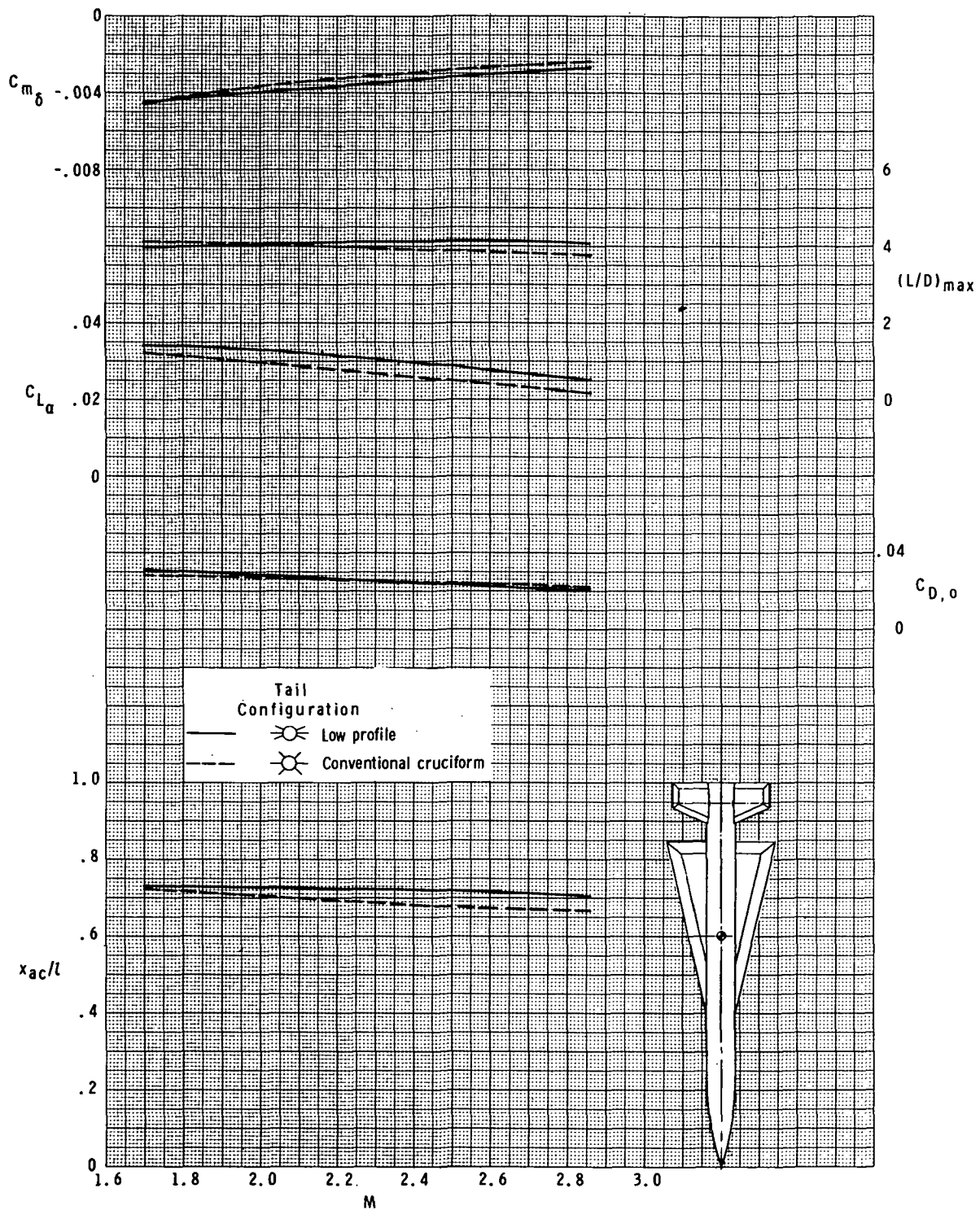


Figure 7.- Summary of longitudinal aerodynamic characteristics.

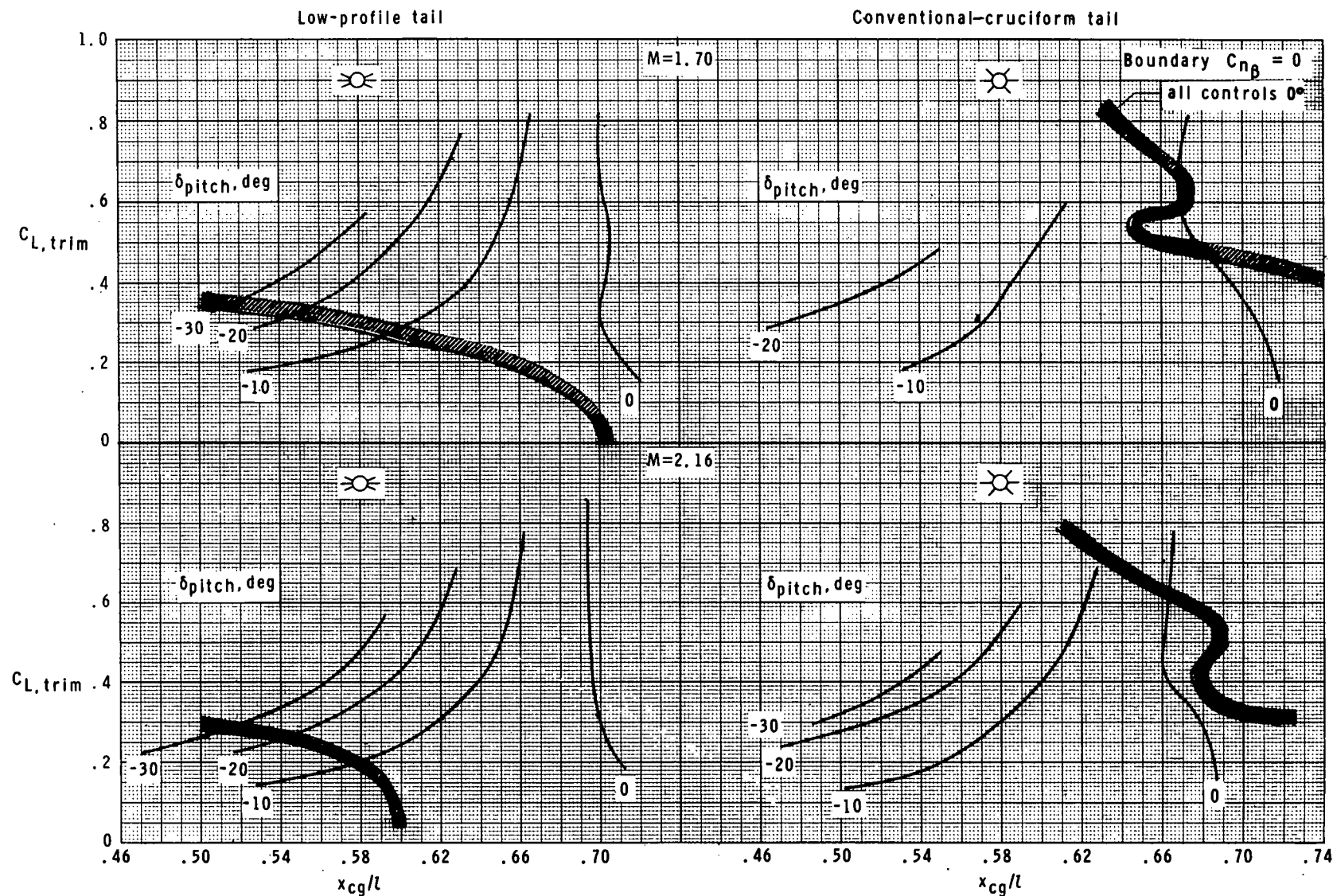


Figure 8.- Comparison of variations of trimmed-lift coefficient with center-of-gravity location for low-profile and conventional-cruciform tail configurations.

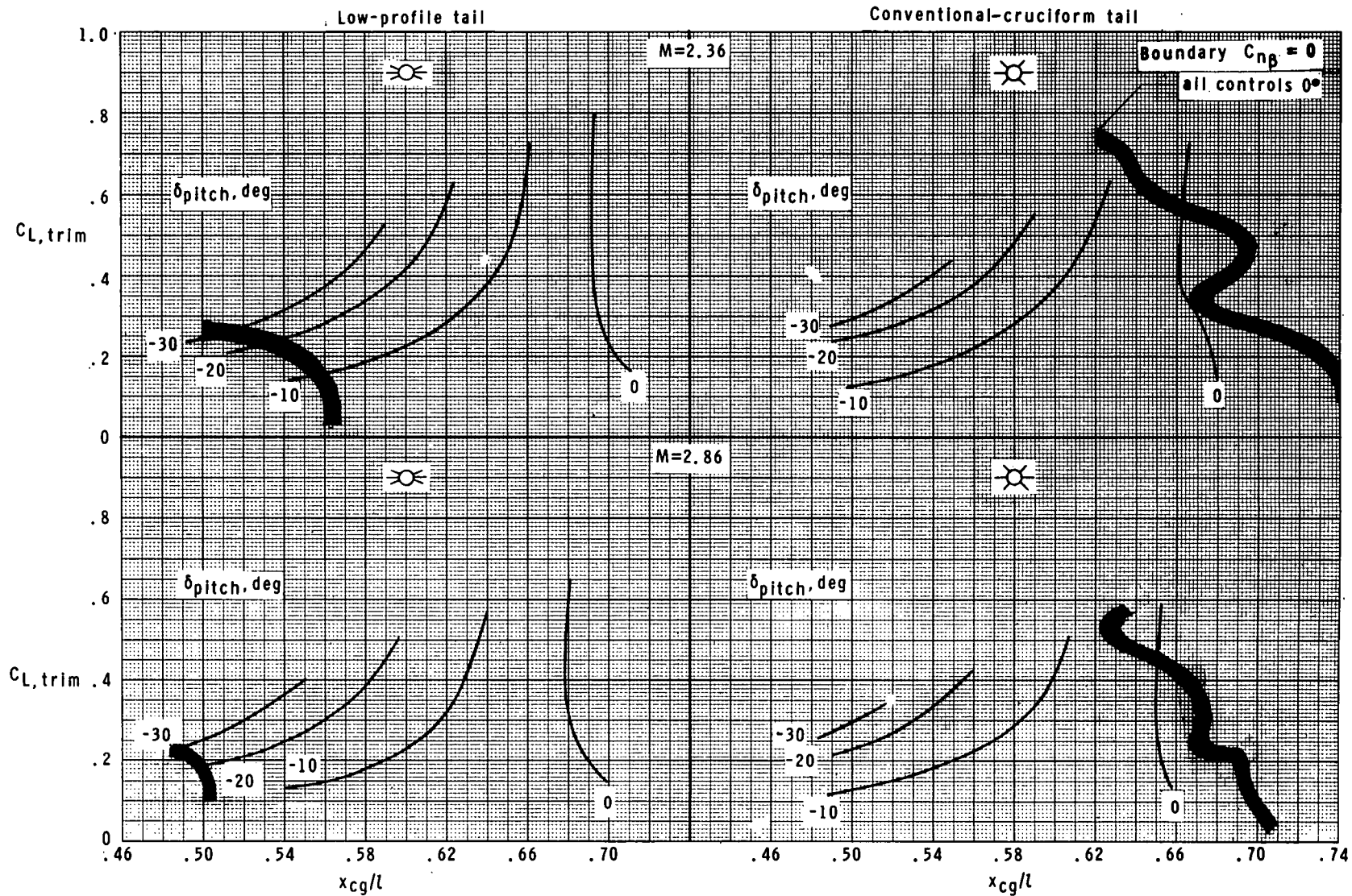
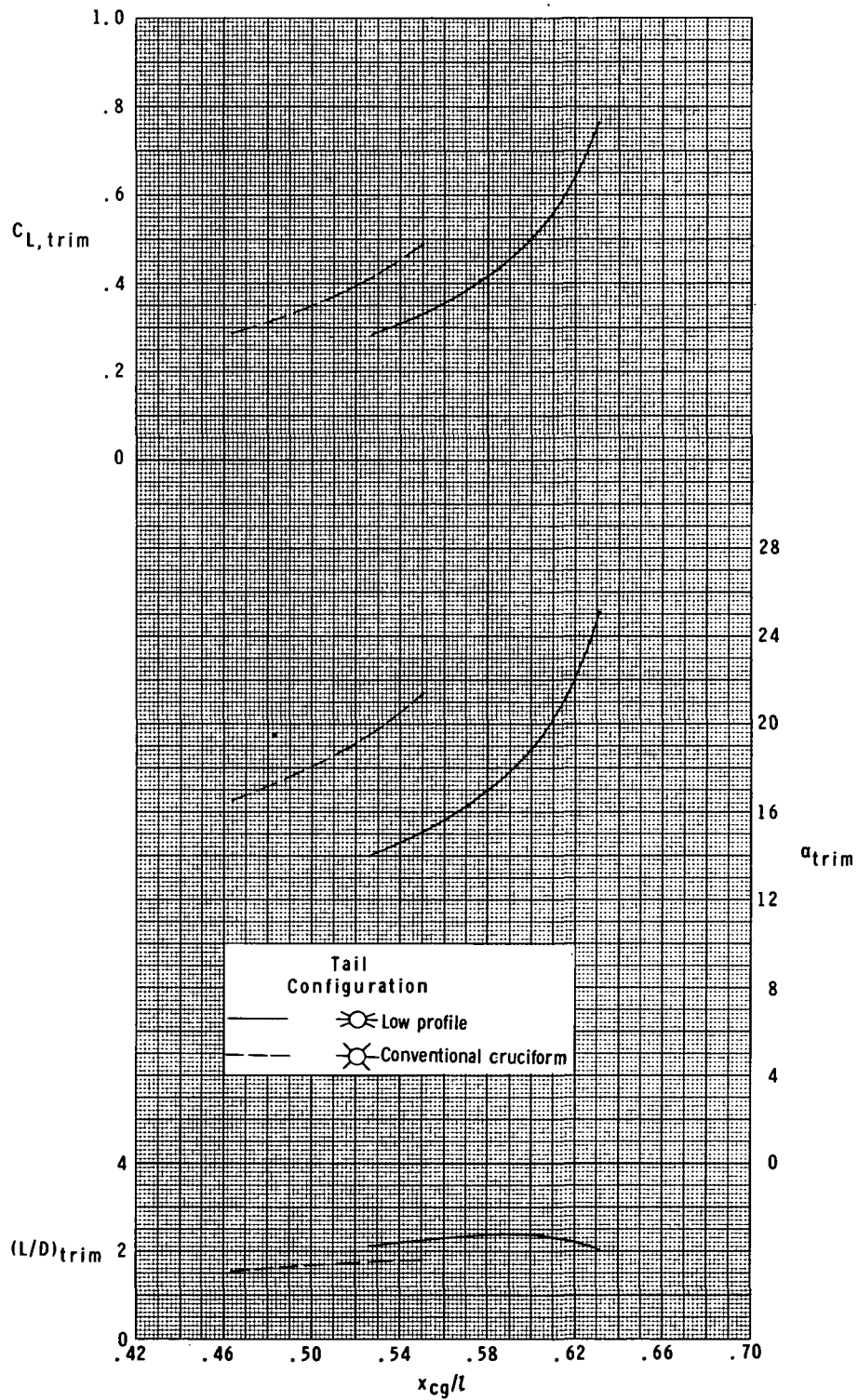
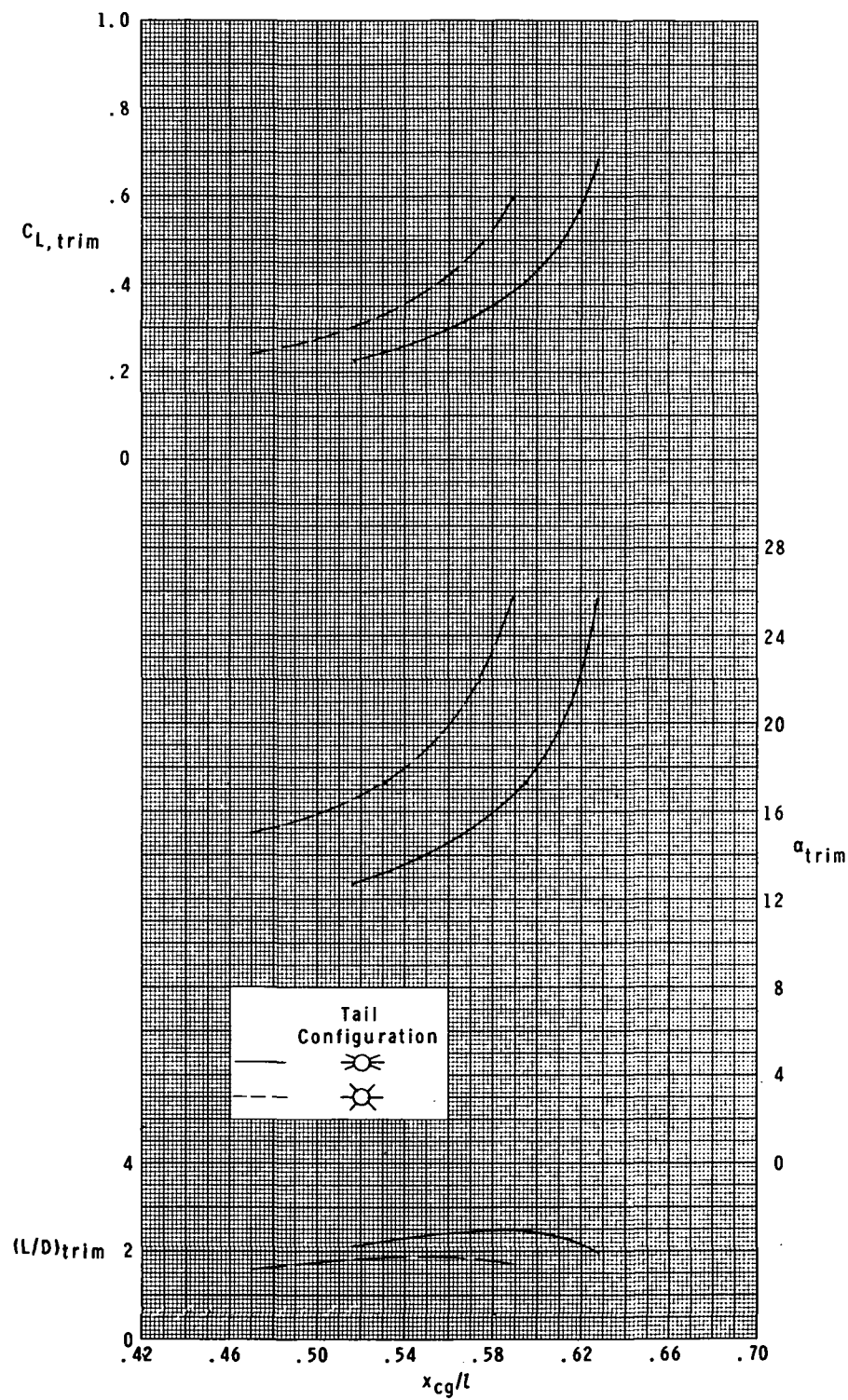


Figure 8.- Concluded.



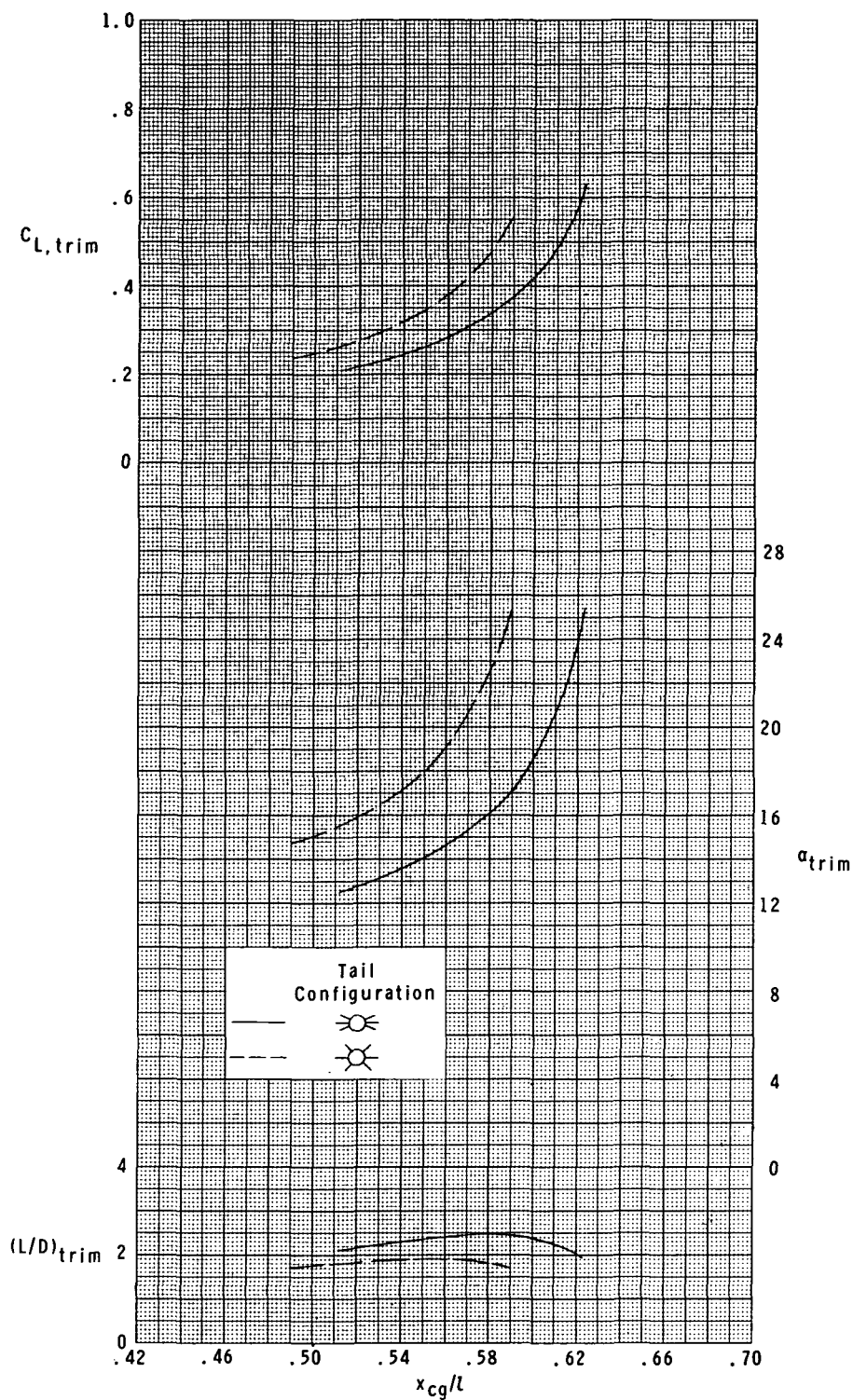
(a) $M = 1.70$.

Figure 9.- Comparison of trim characteristics for the two tail configurations at $\delta_{pitch} = -20^\circ$.



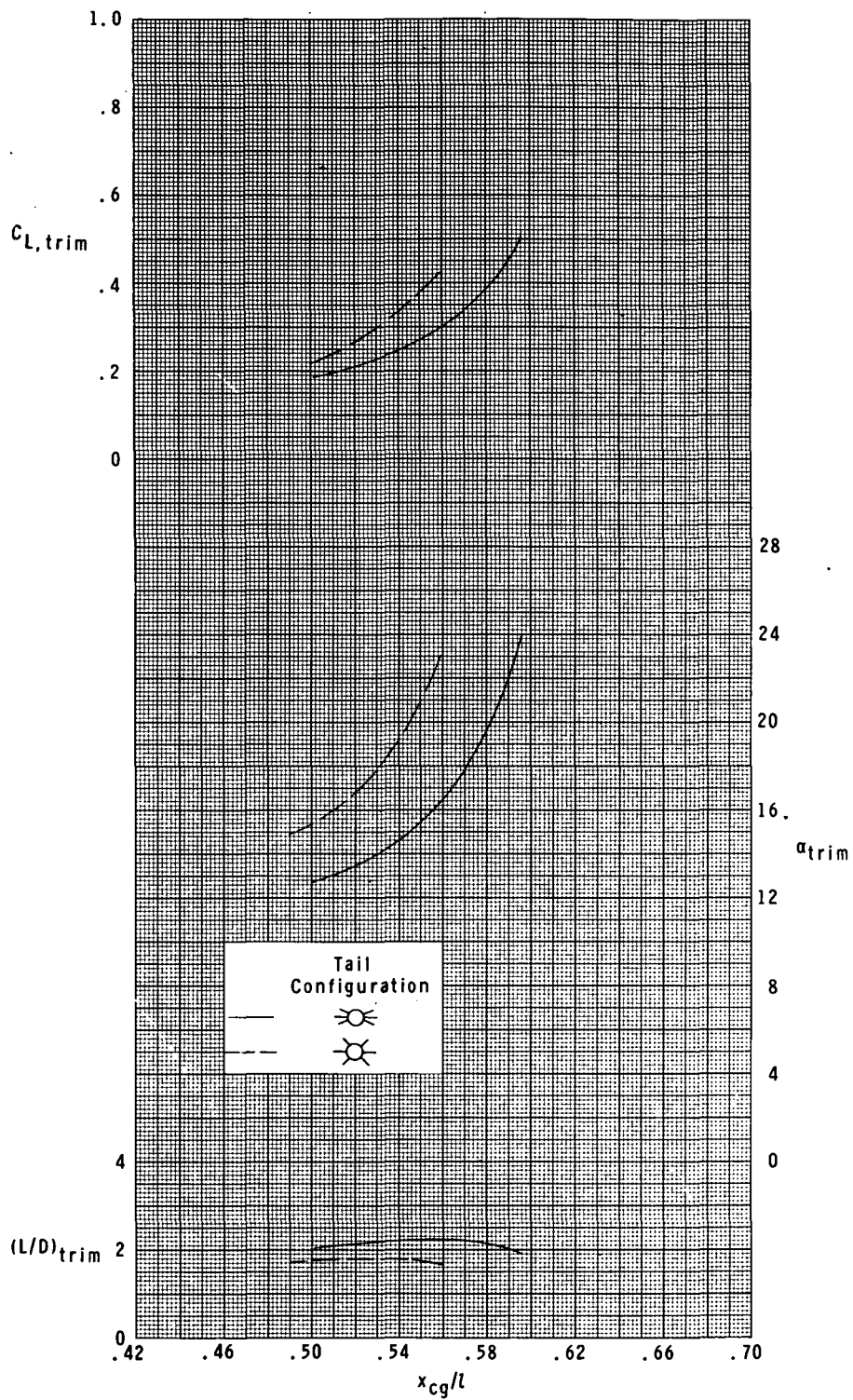
(b) $M = 2.16$.

Figure 9.- Continued.



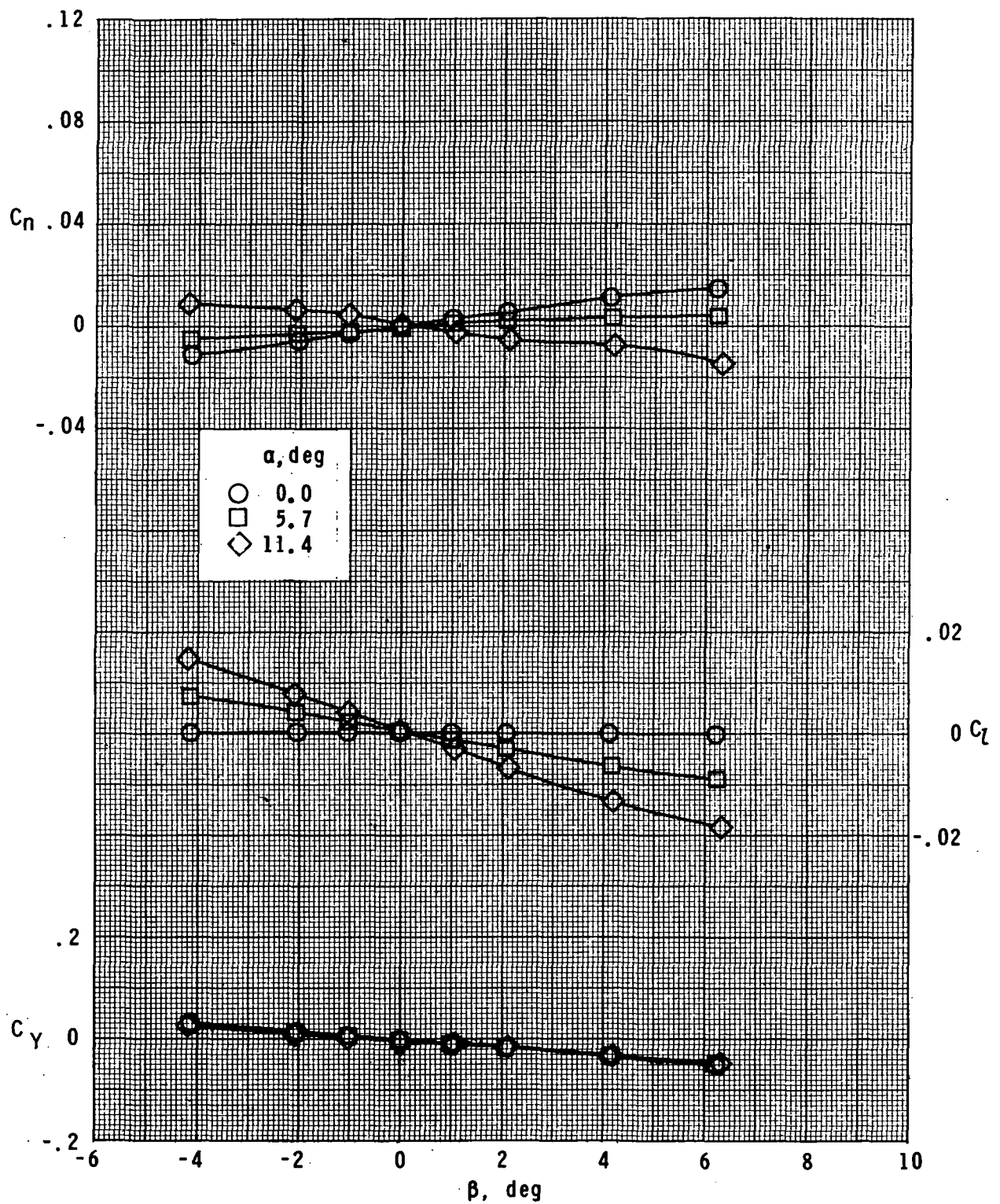
(c) $M = 2.36$.

Figure 9.- Continued.



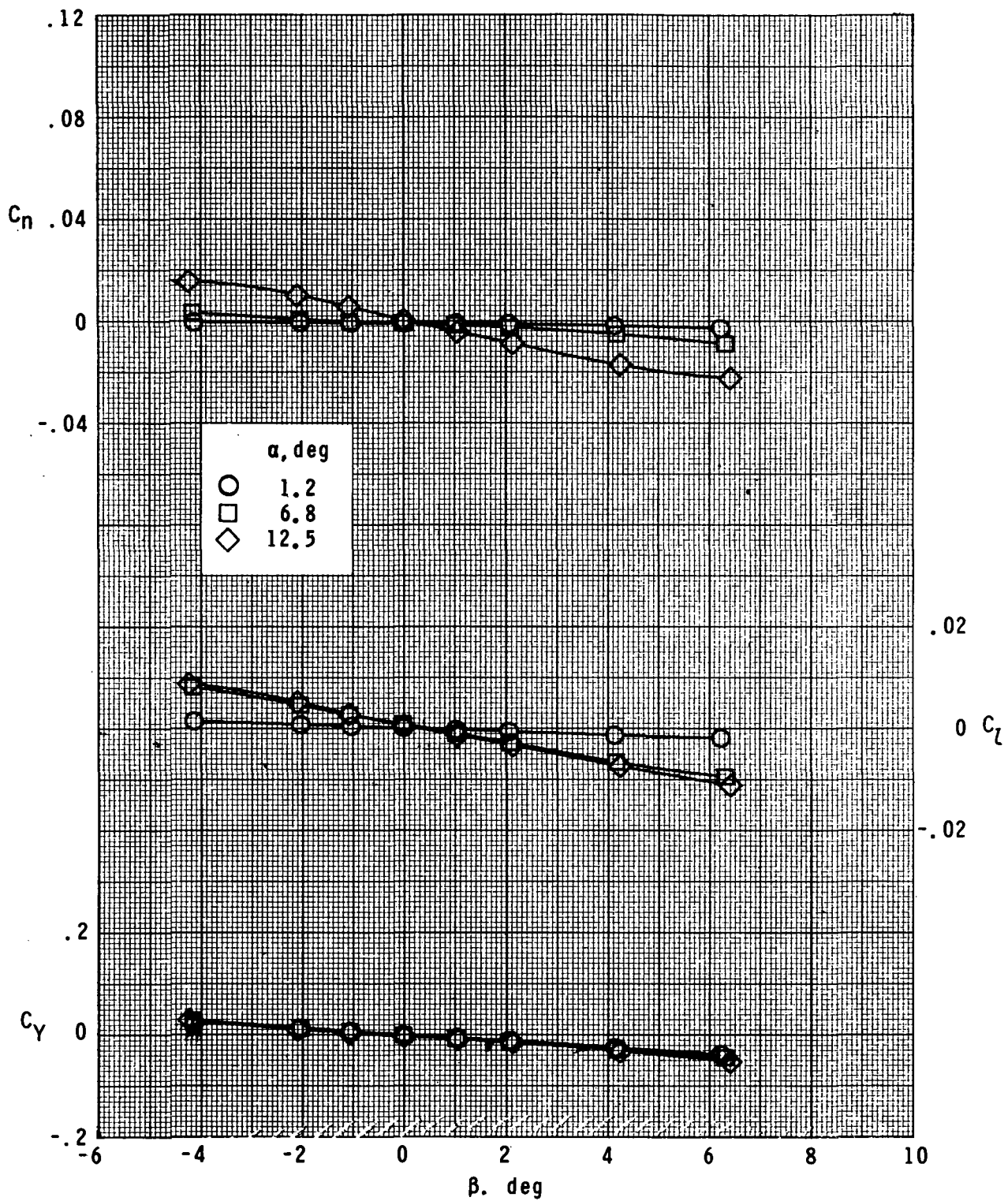
(d) $M = 2.86$.

Figure 9.- Concluded.



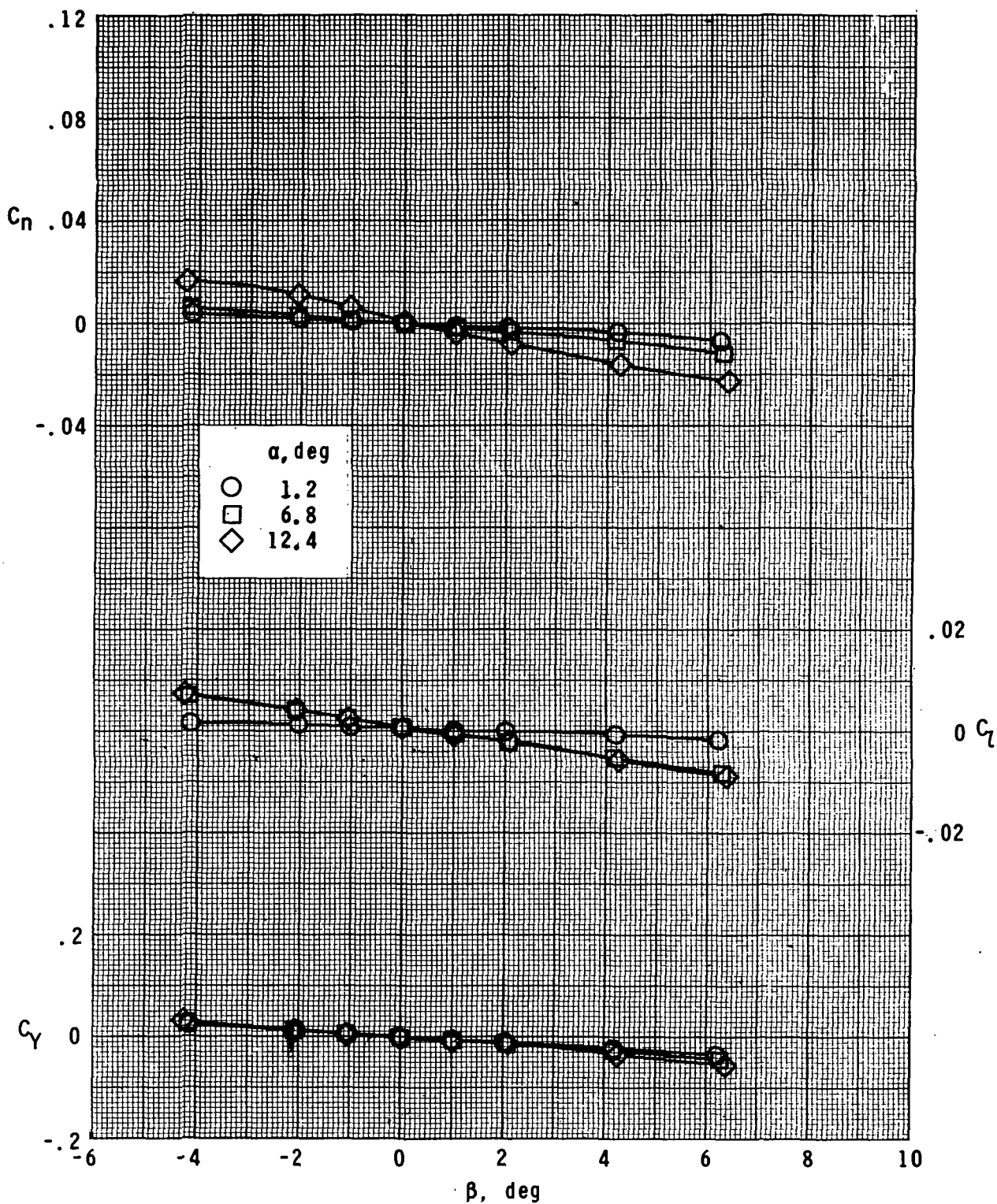
(a) $M = 1.70$.

Figure 10.- Lateral characteristics as a function of sideslip angle with all controls 0° for low-profile tail.



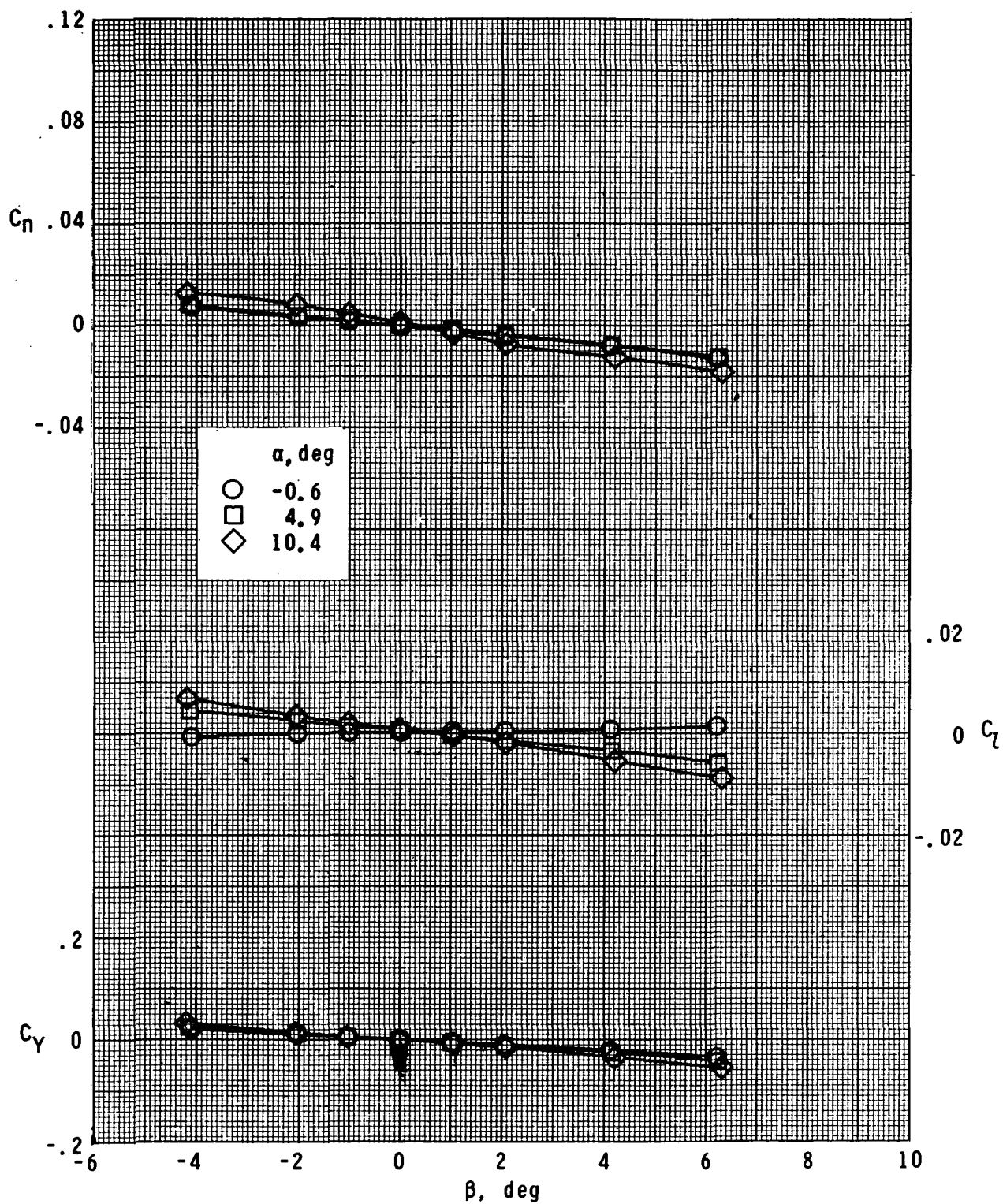
(b) $M = 2.16$.

Figure 10:- Continued.



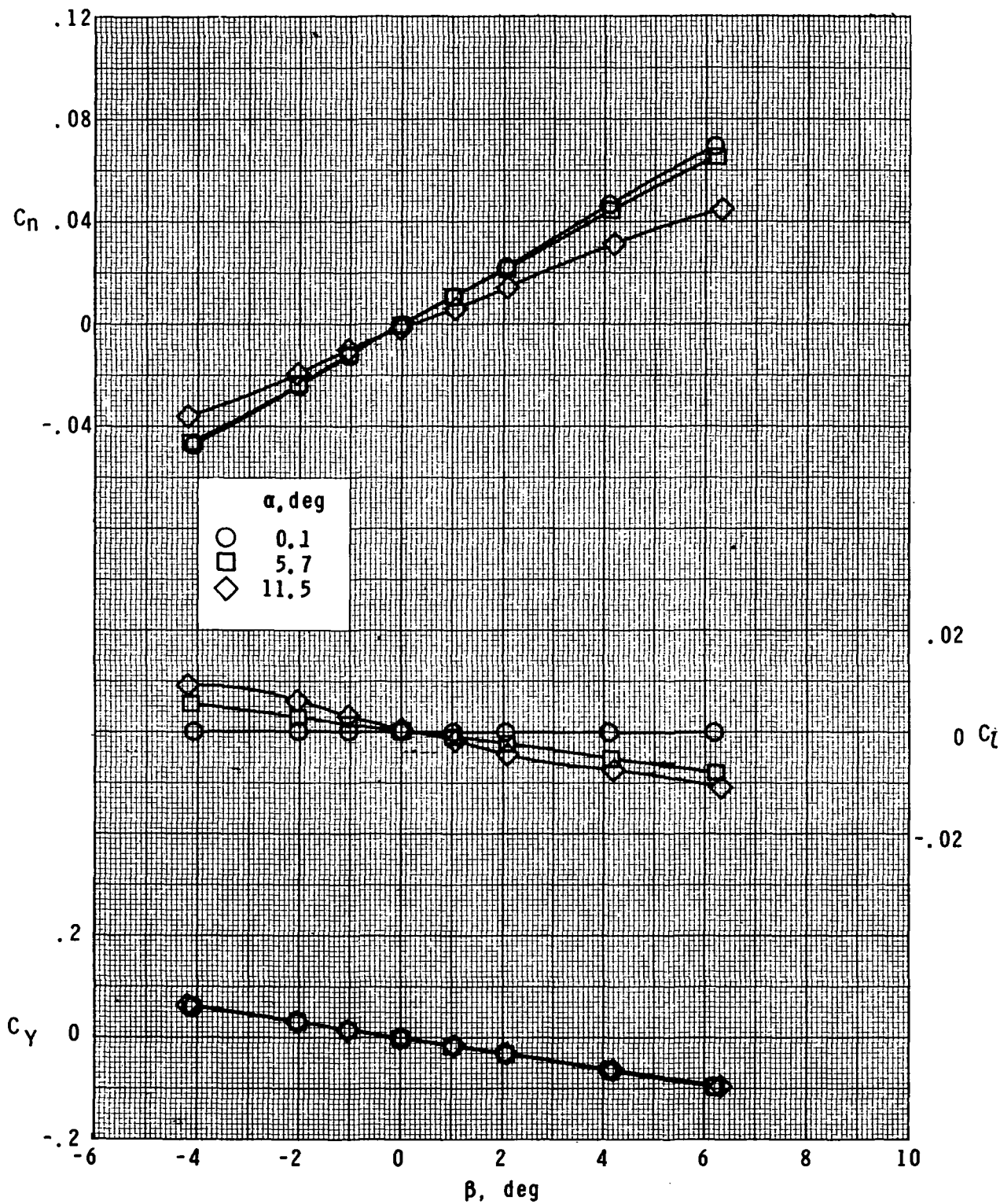
(c) $M = 2.36$.

Figure 10.- Continued.



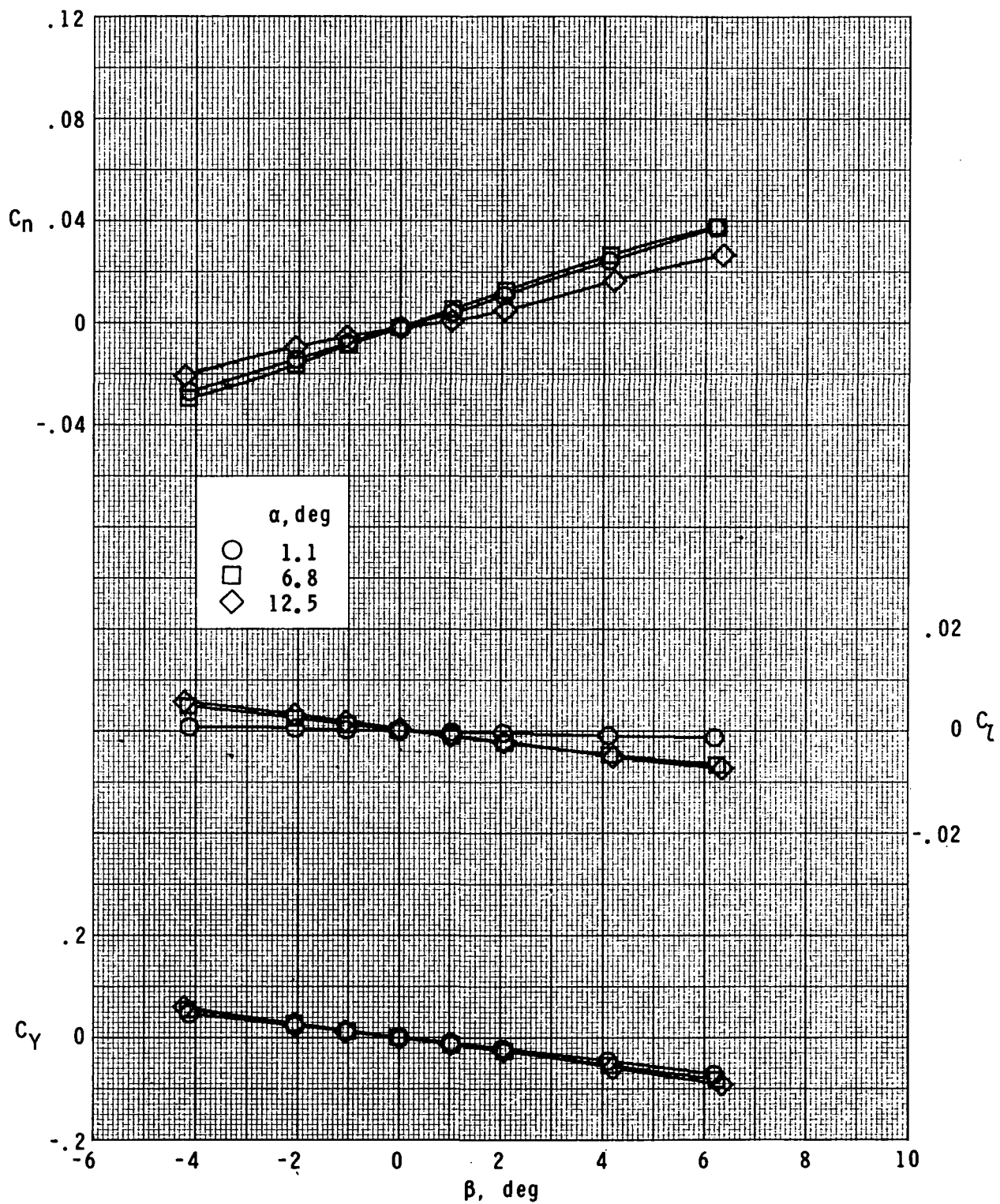
(d) $M = 2.86$.

Figure 10.- Concluded.



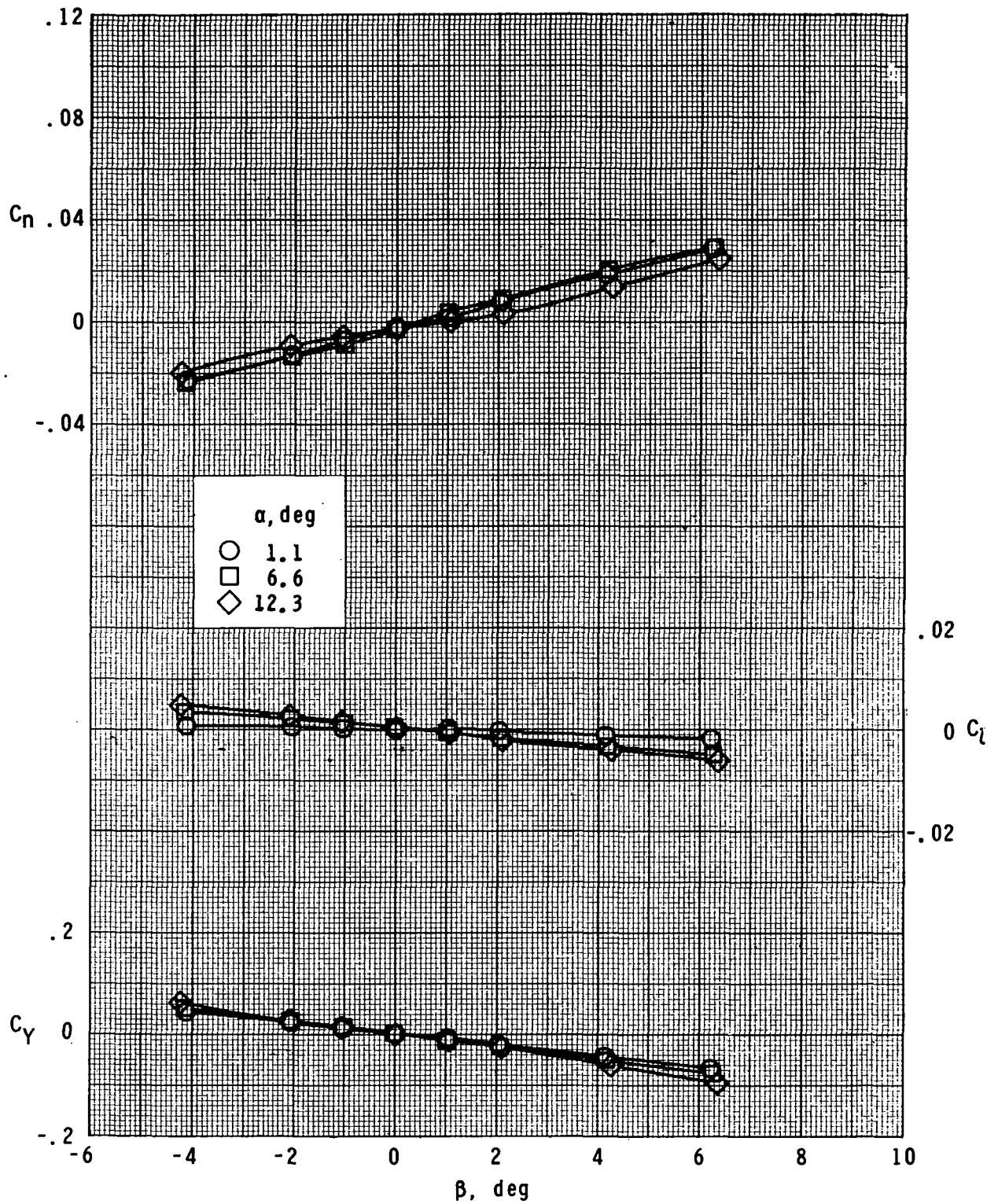
(a) $M = 1.70$.

Figure 11.- Lateral characteristics as a function of sideslip angle with all controls 0° for conventional-cruciform tail.



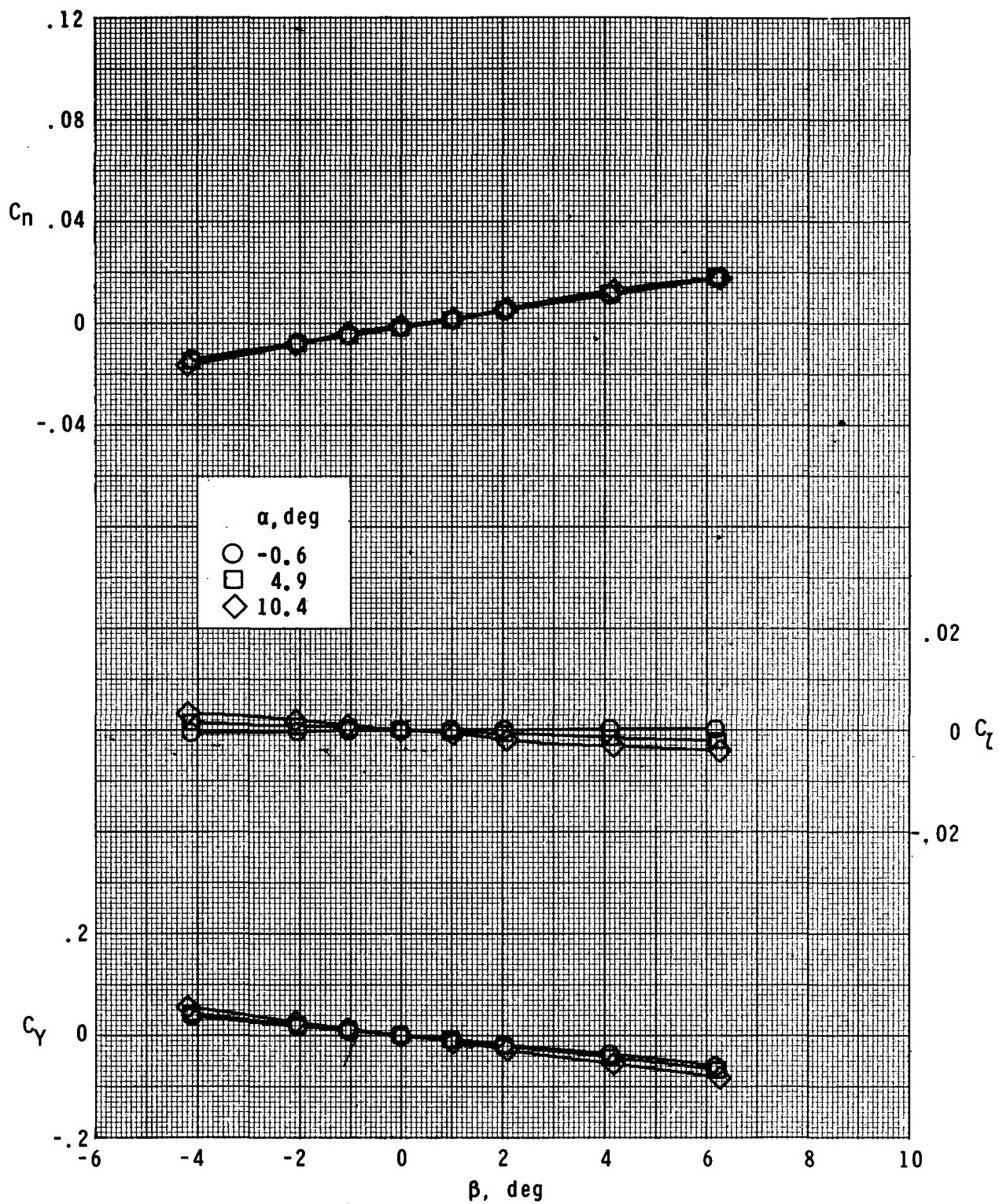
(b) $M = 2.16$.

Figure 11.- Continued.



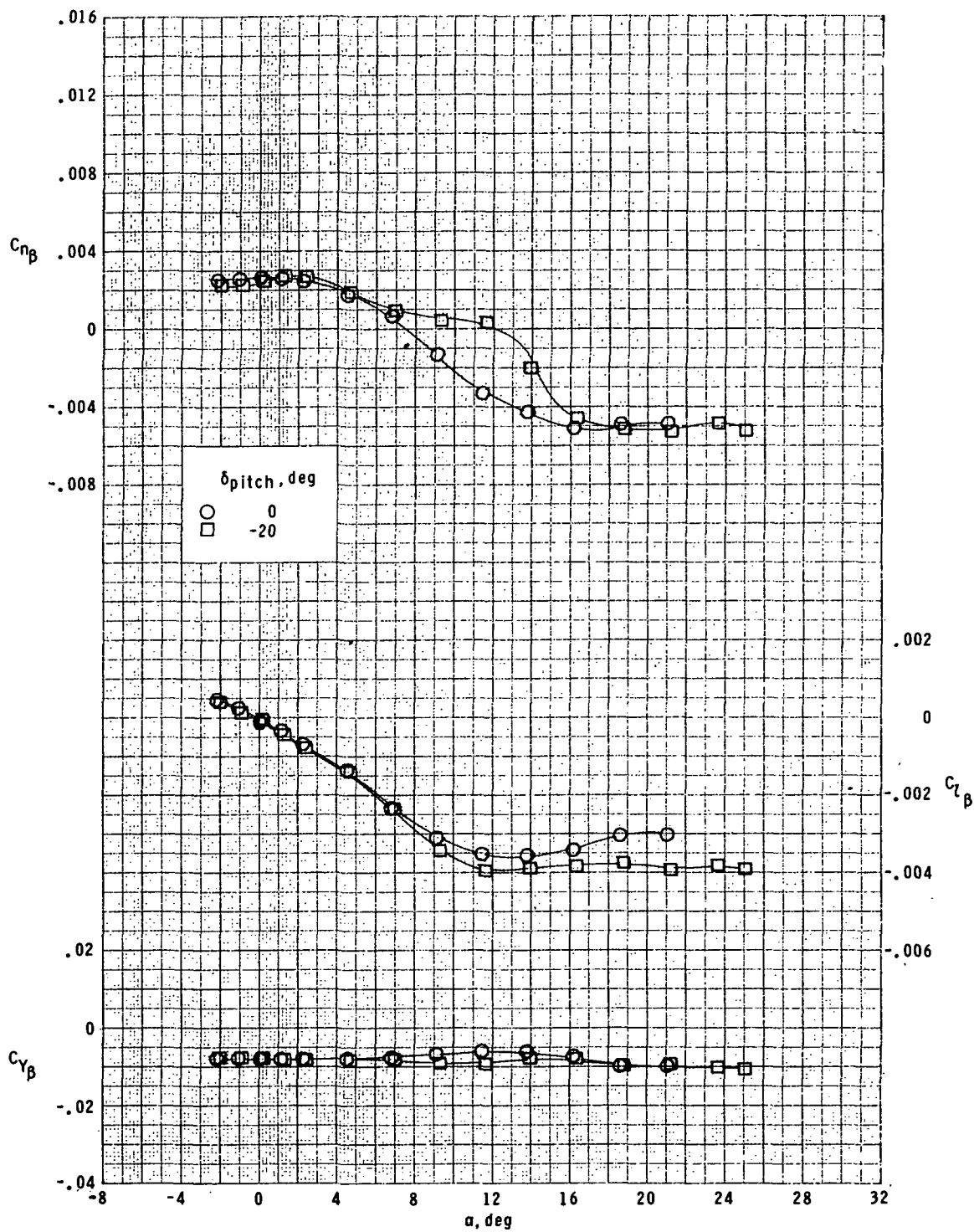
(c) $M = 2.36$.

Figure 11.- Continued.



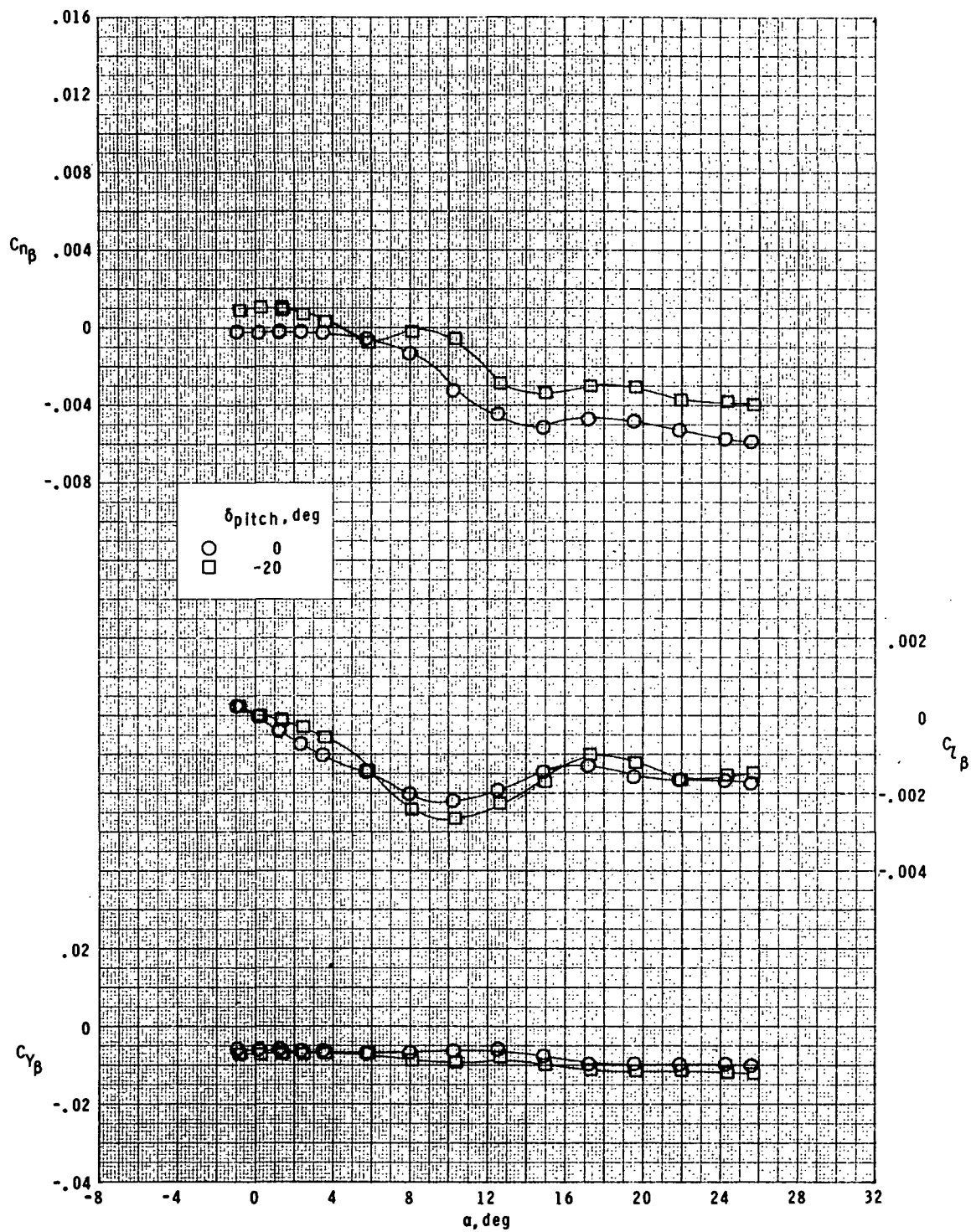
(d) $M = 2.86$.

Figure 11.- Concluded.



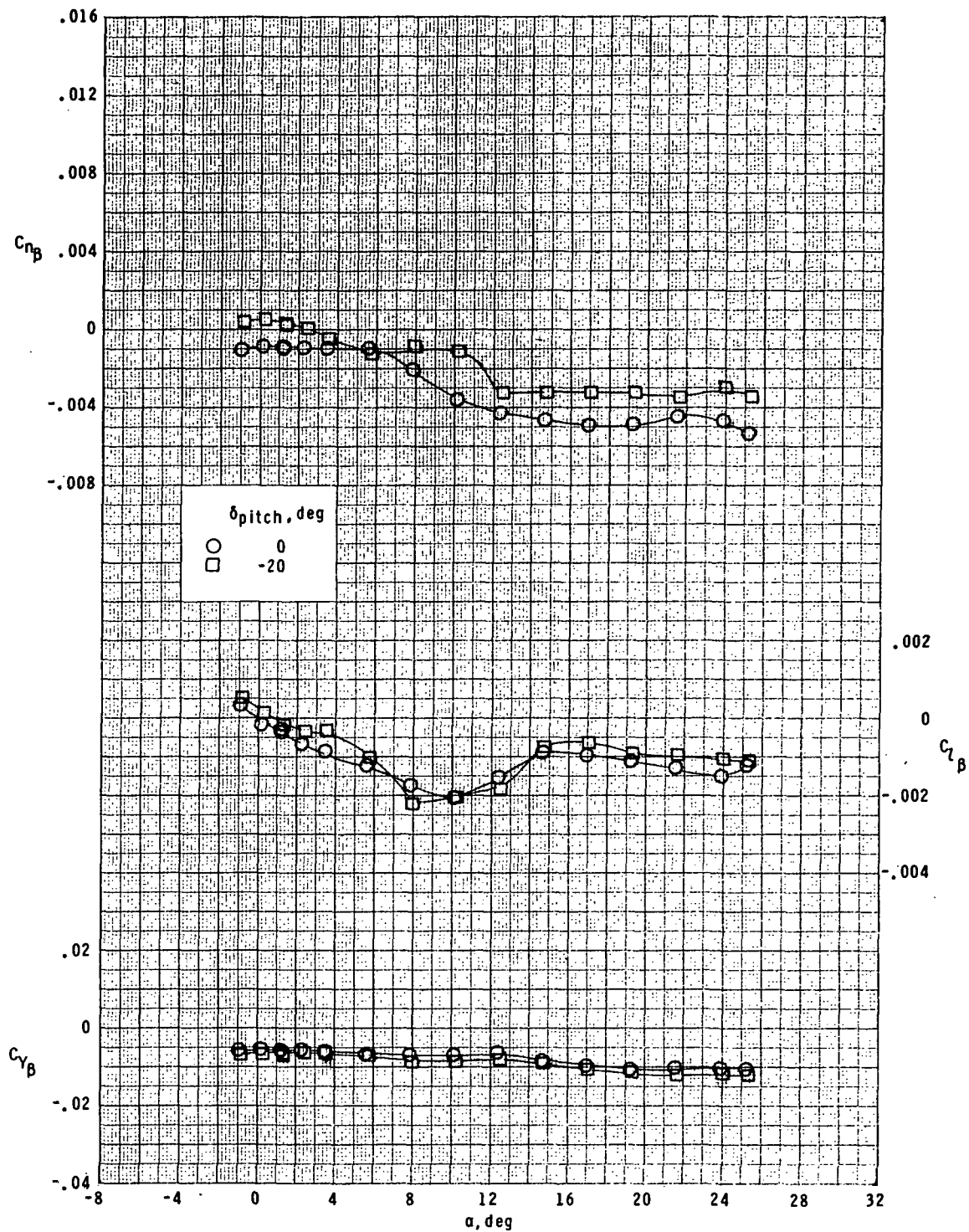
(a) $M = 1.70$.

Figure 12.- Effect of pitch control on lateral parameters for low-profile tail.



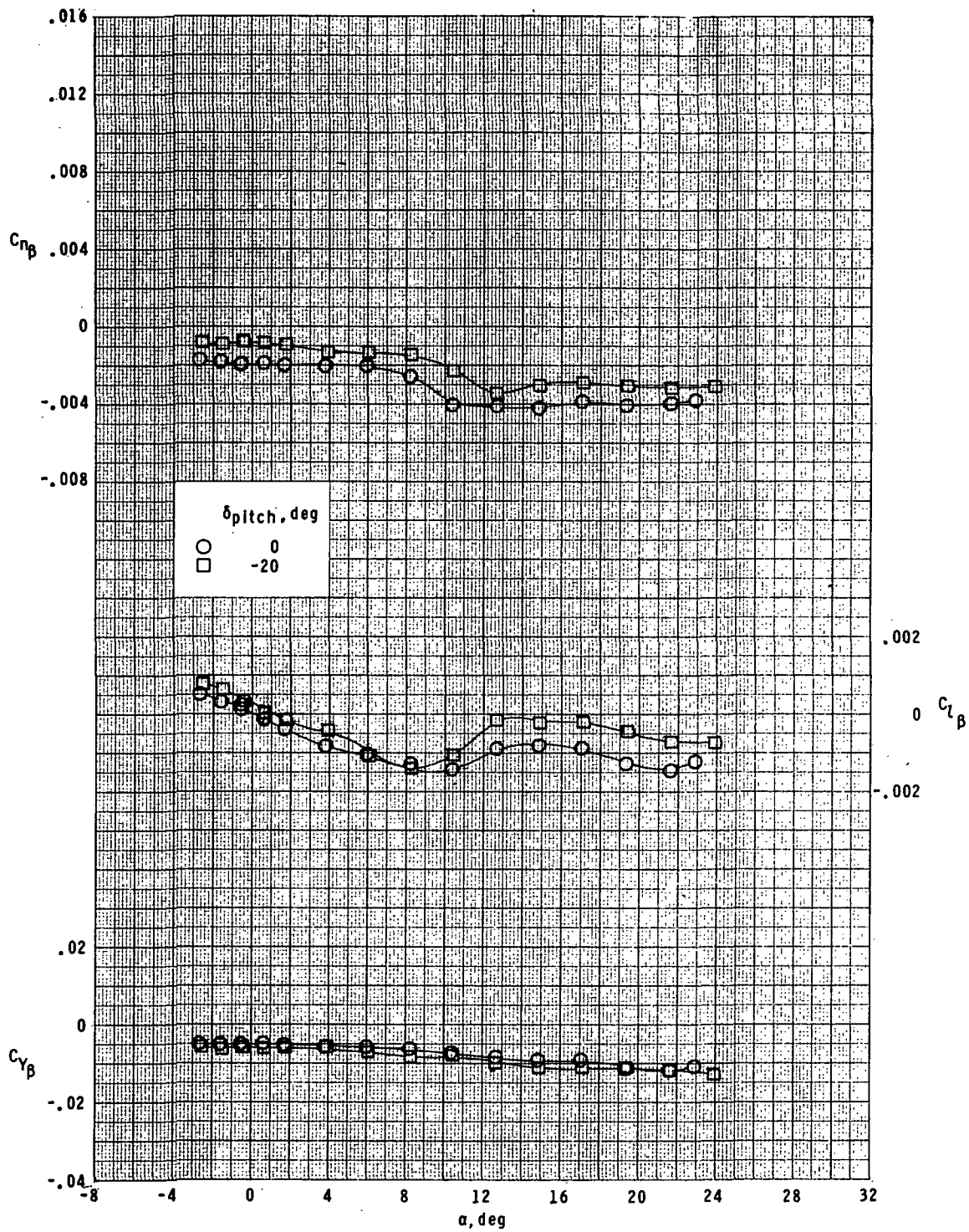
(b) $M = 2.16$.

Figure 12.- Continued.



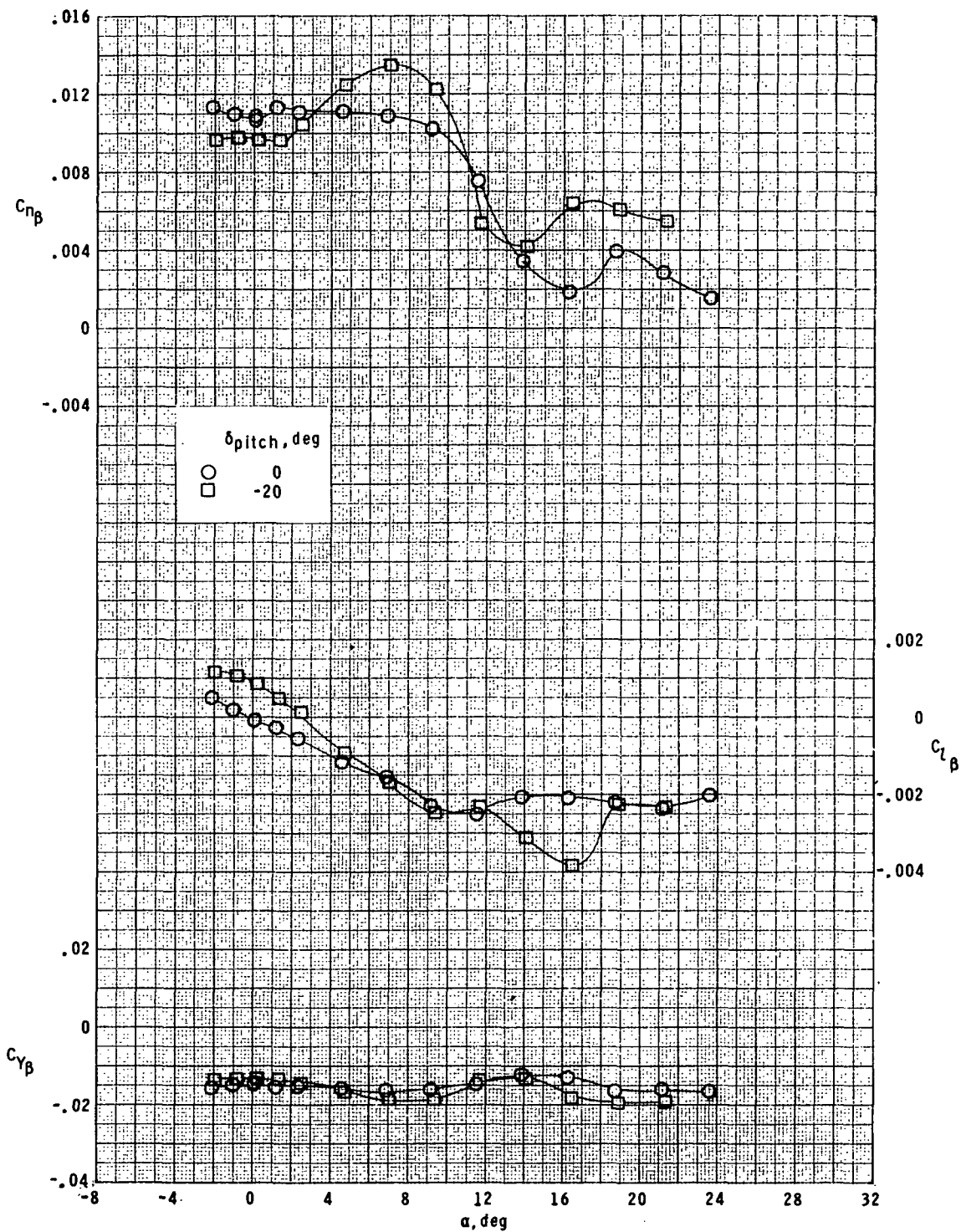
(c) $M = 2.36$.

Figure 12.- Continued.



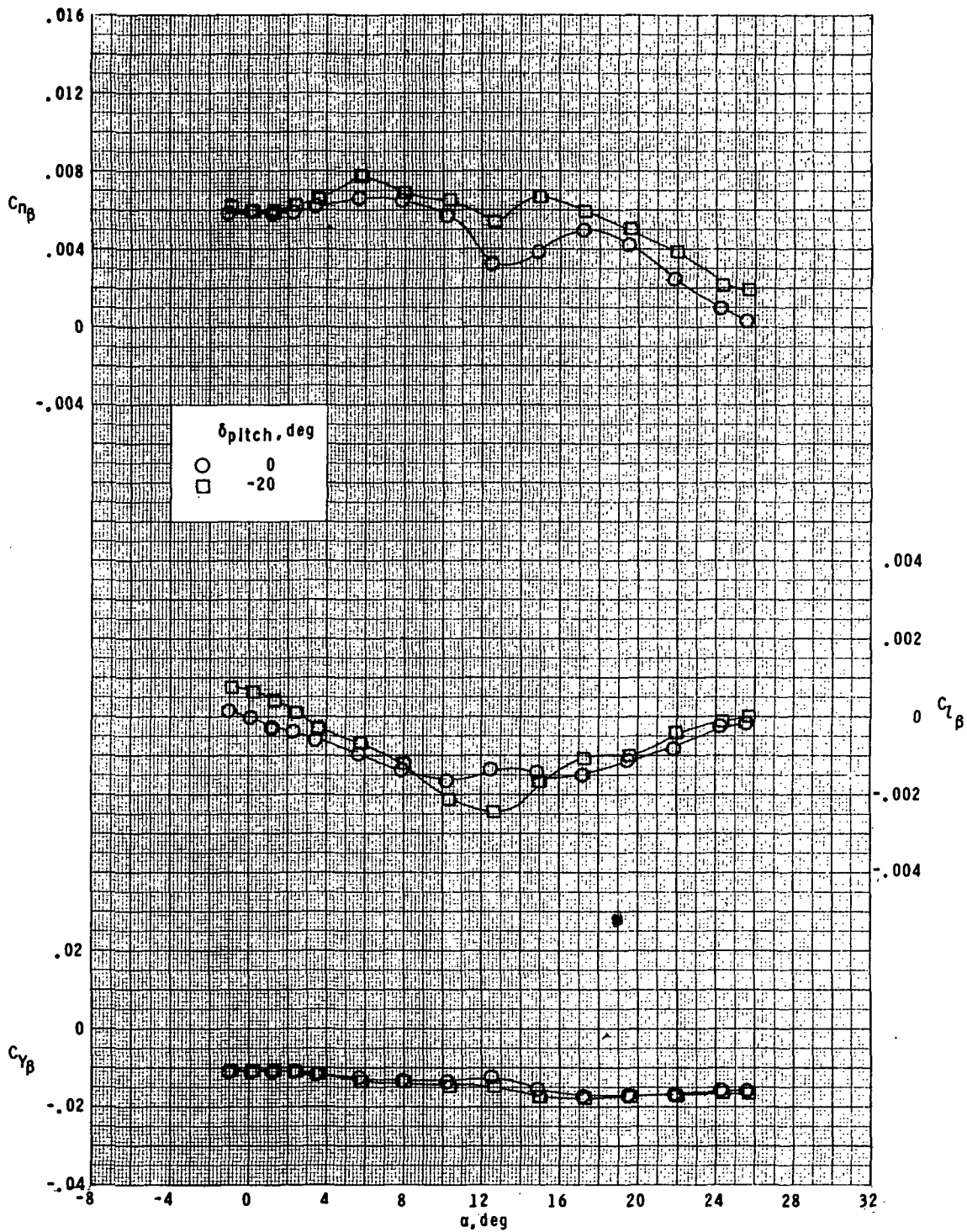
(d) $M = 2.86$.

Figure 12.- Concluded.



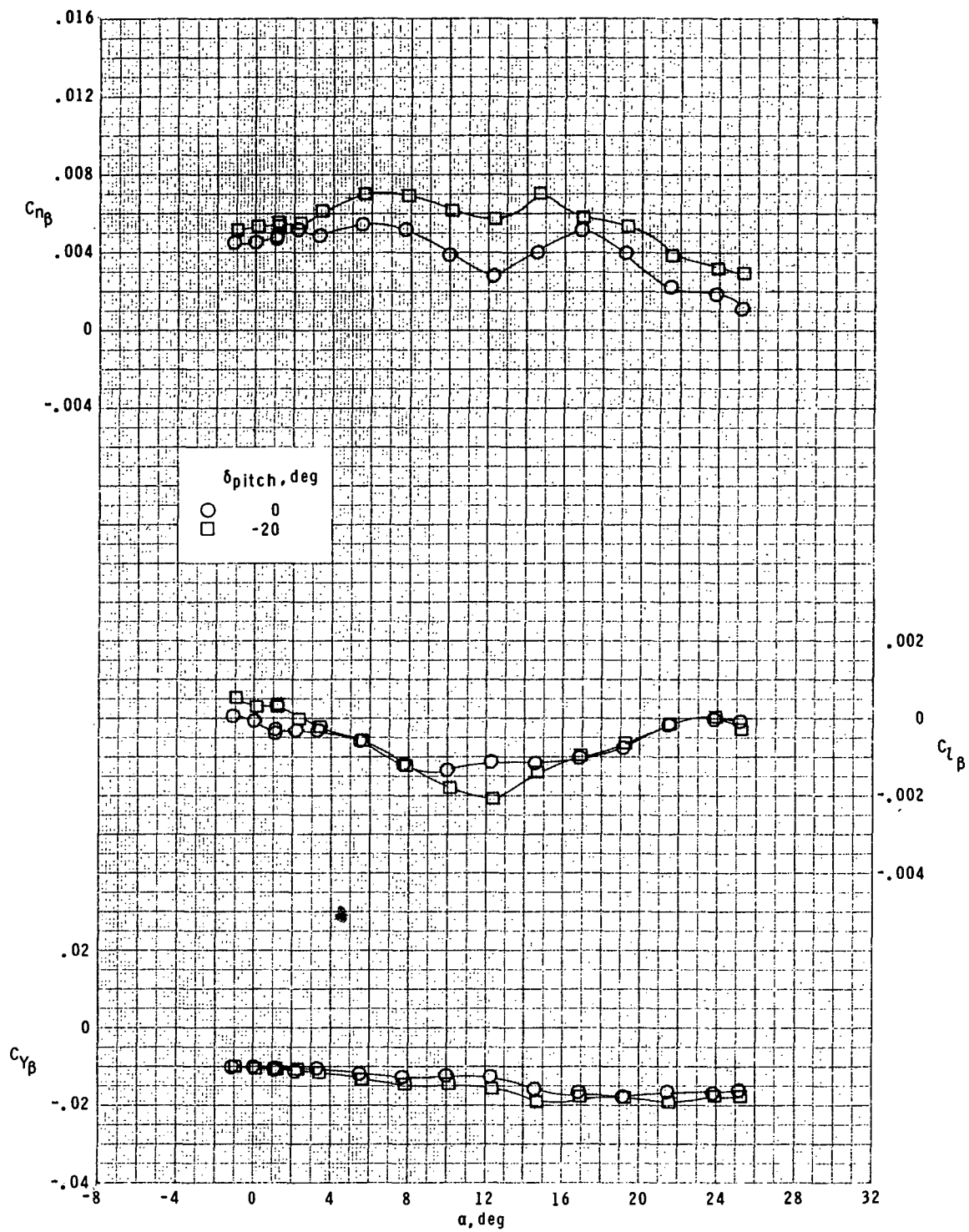
(a) $M = 1.70$.

Figure 13.- Effect of pitch control on lateral parameters for conventional-cruciform tail.



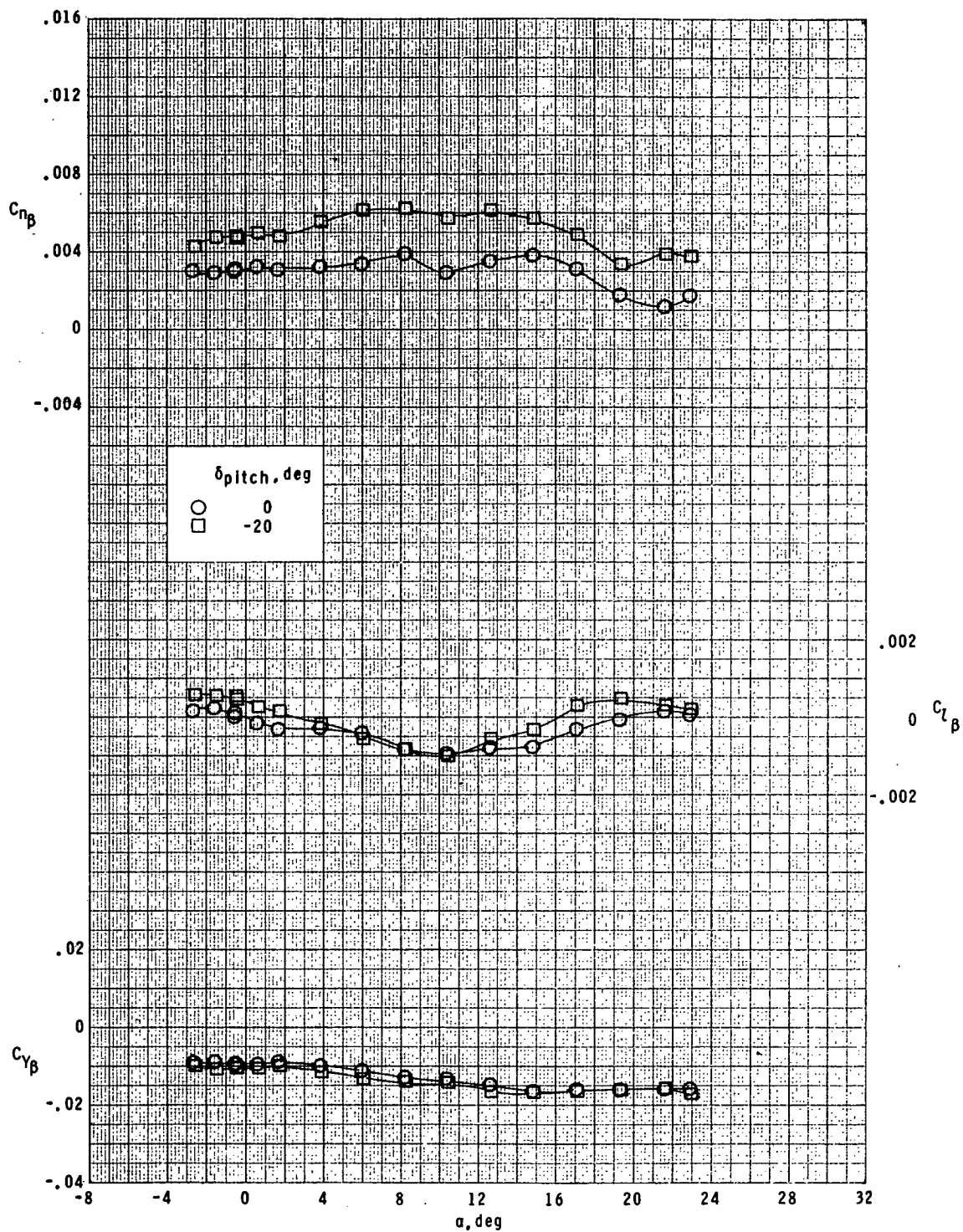
(b) $M = 2.16$.

Figure 13.- Continued.



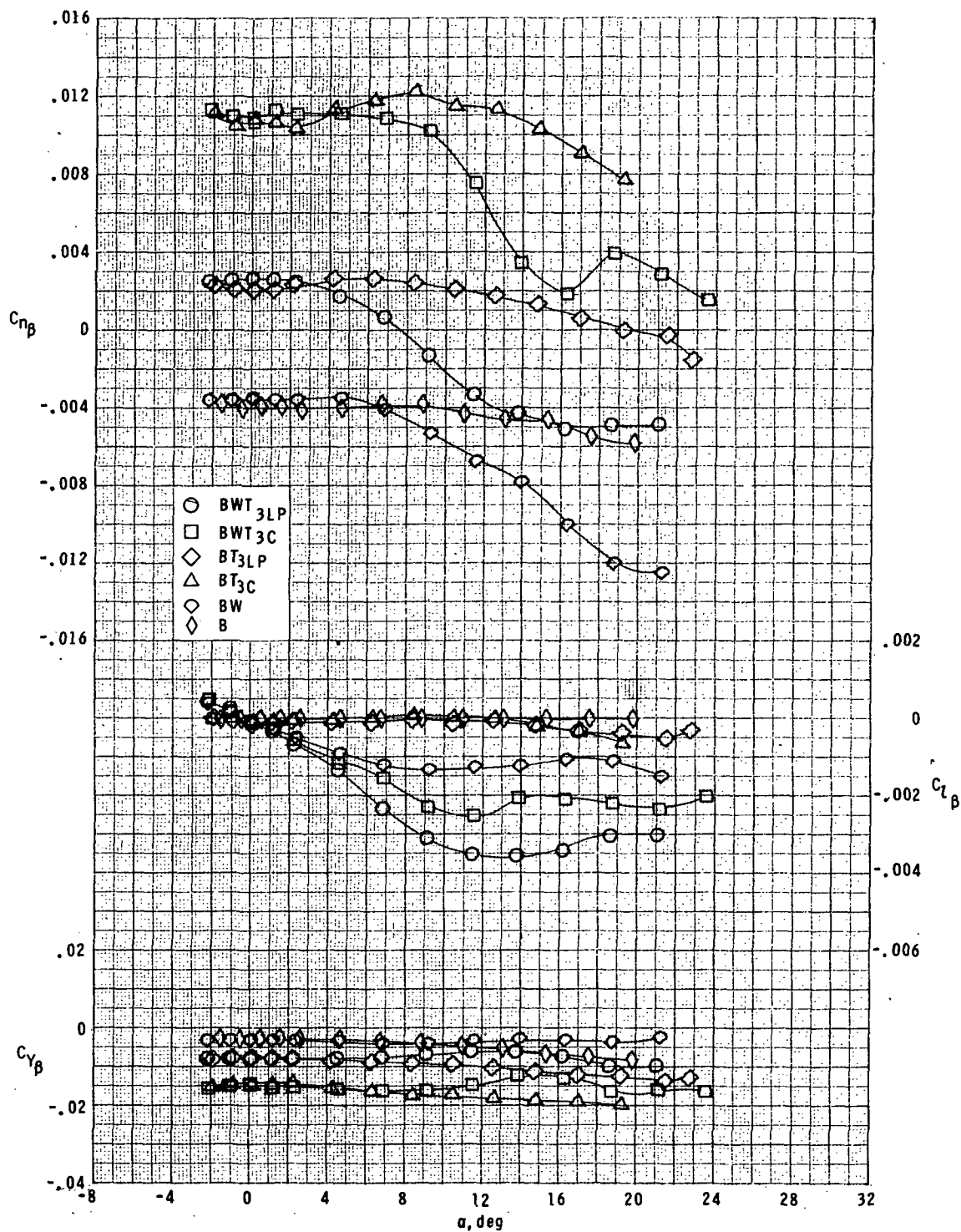
(c) $M = 2.36$.

Figure 13.- Continued.



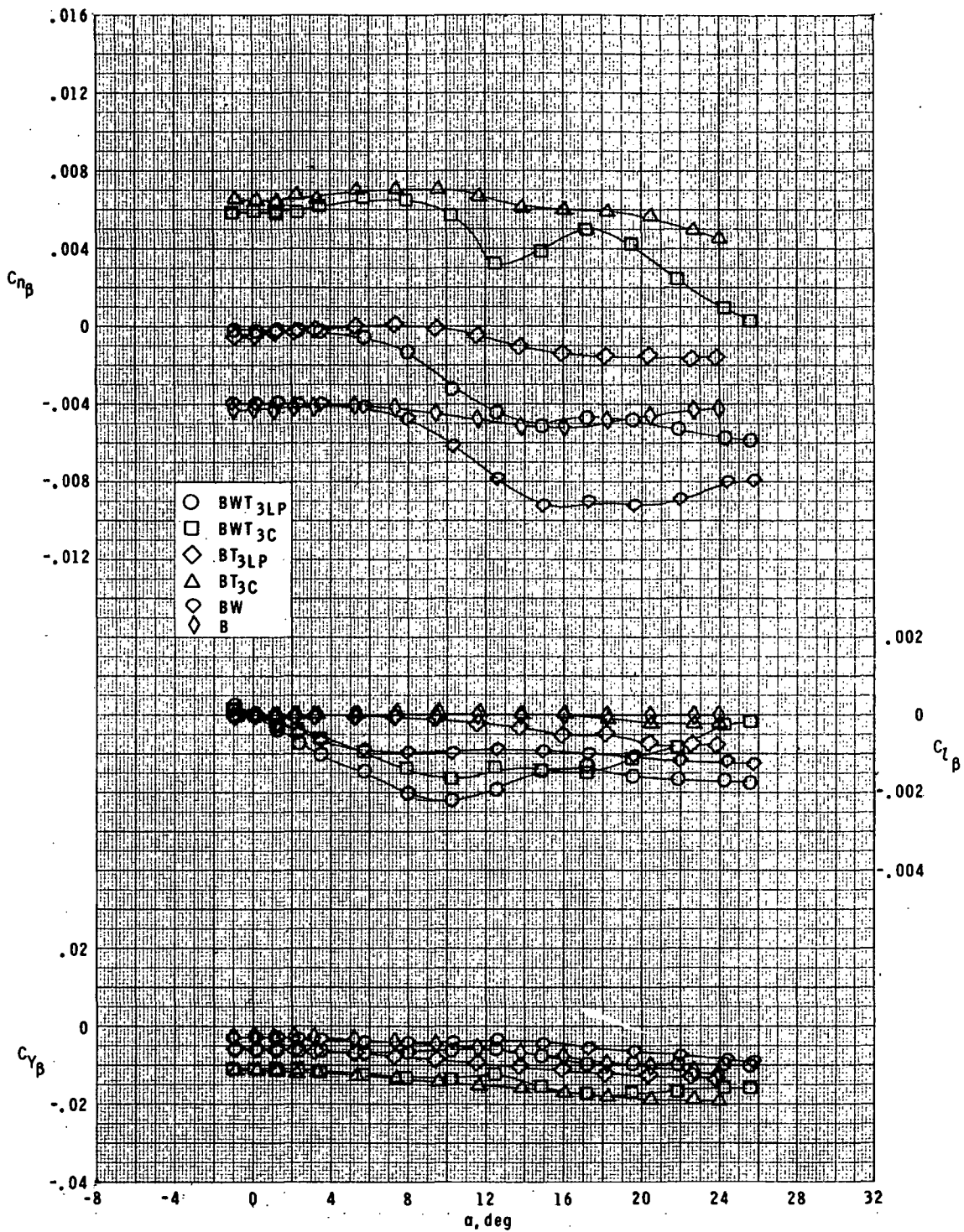
(d) $M = 2.86$.

Figure 13.- Concluded.



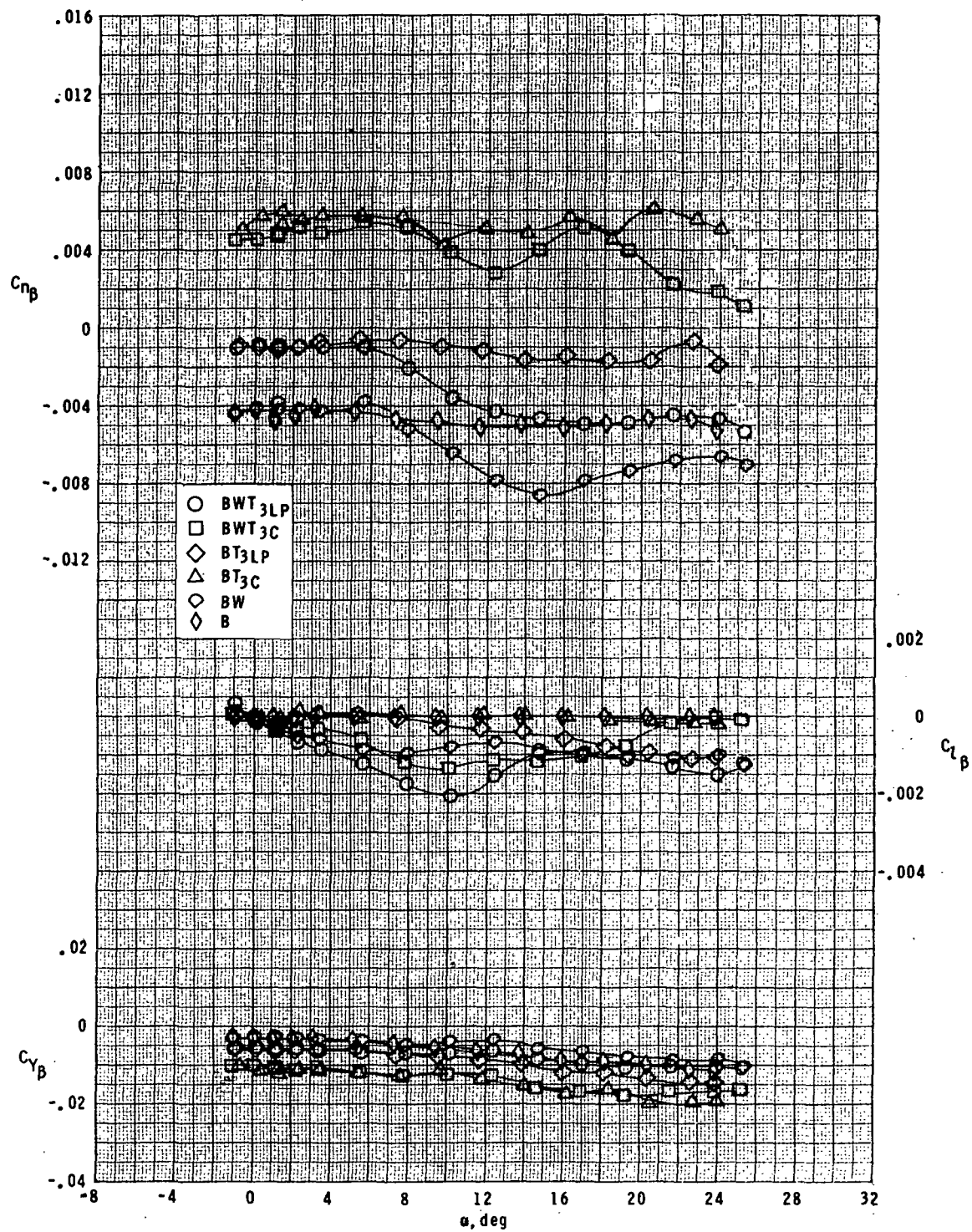
(a) $M = 1.70$.

Figure 14.- Effect of model components on lateral parameters for low-profile and conventional-cruciform tail configurations.



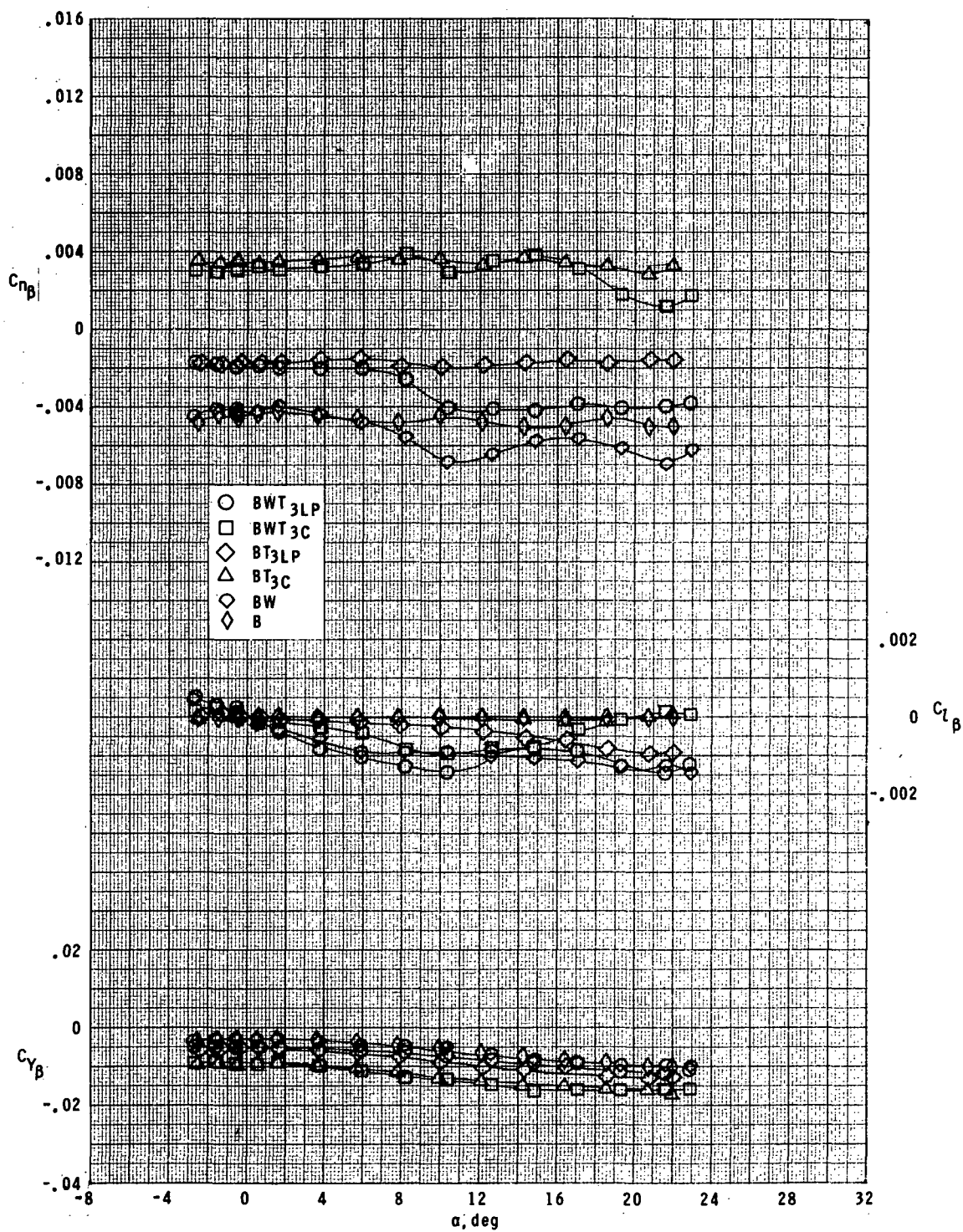
(b) $M = 2.16$.

Figure 14.- Continued.



(c) $M = 2.36$.

Figure 14.- Continued.



(d) $M = 2.86$.

Figure 14.- Concluded.

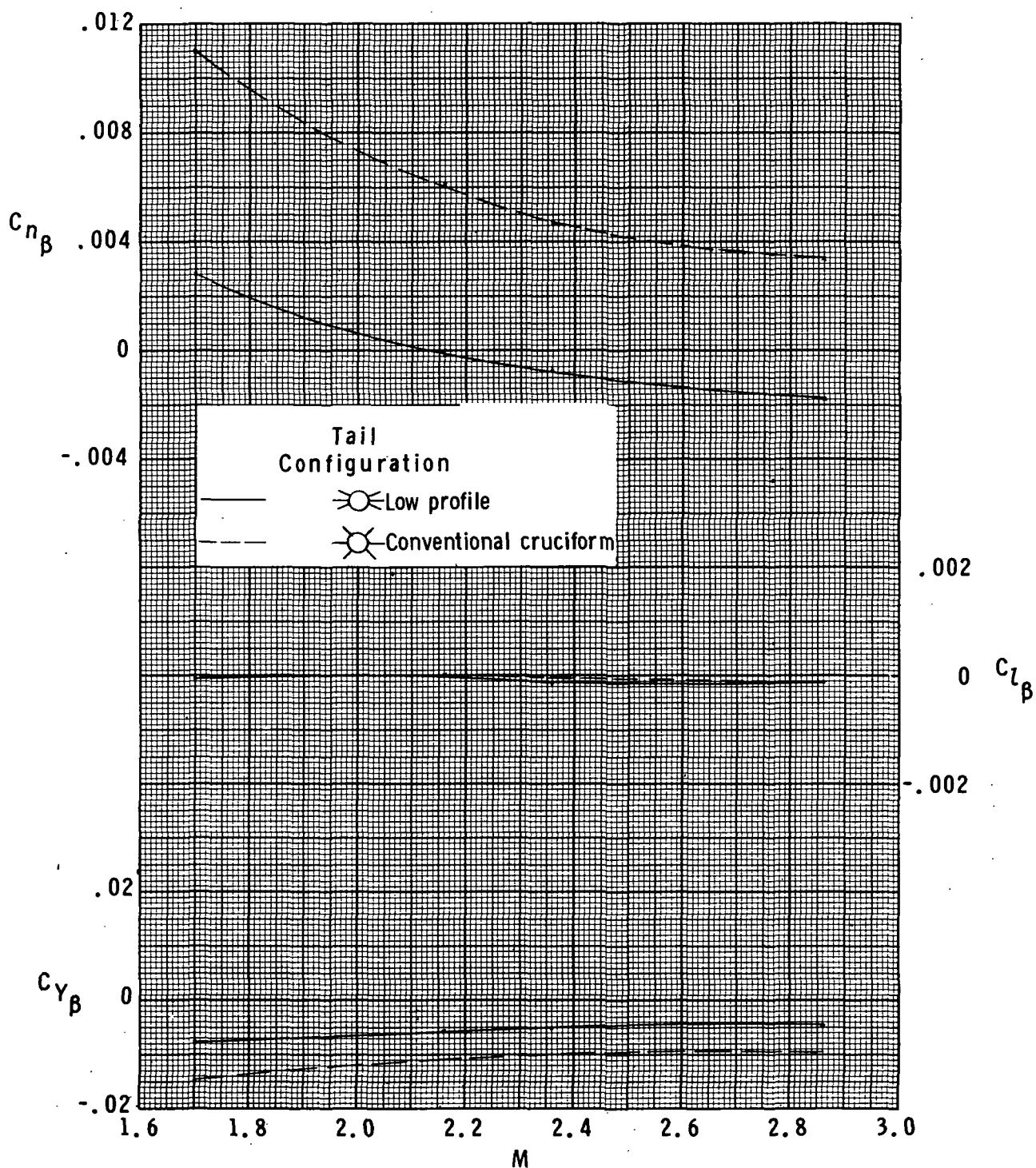
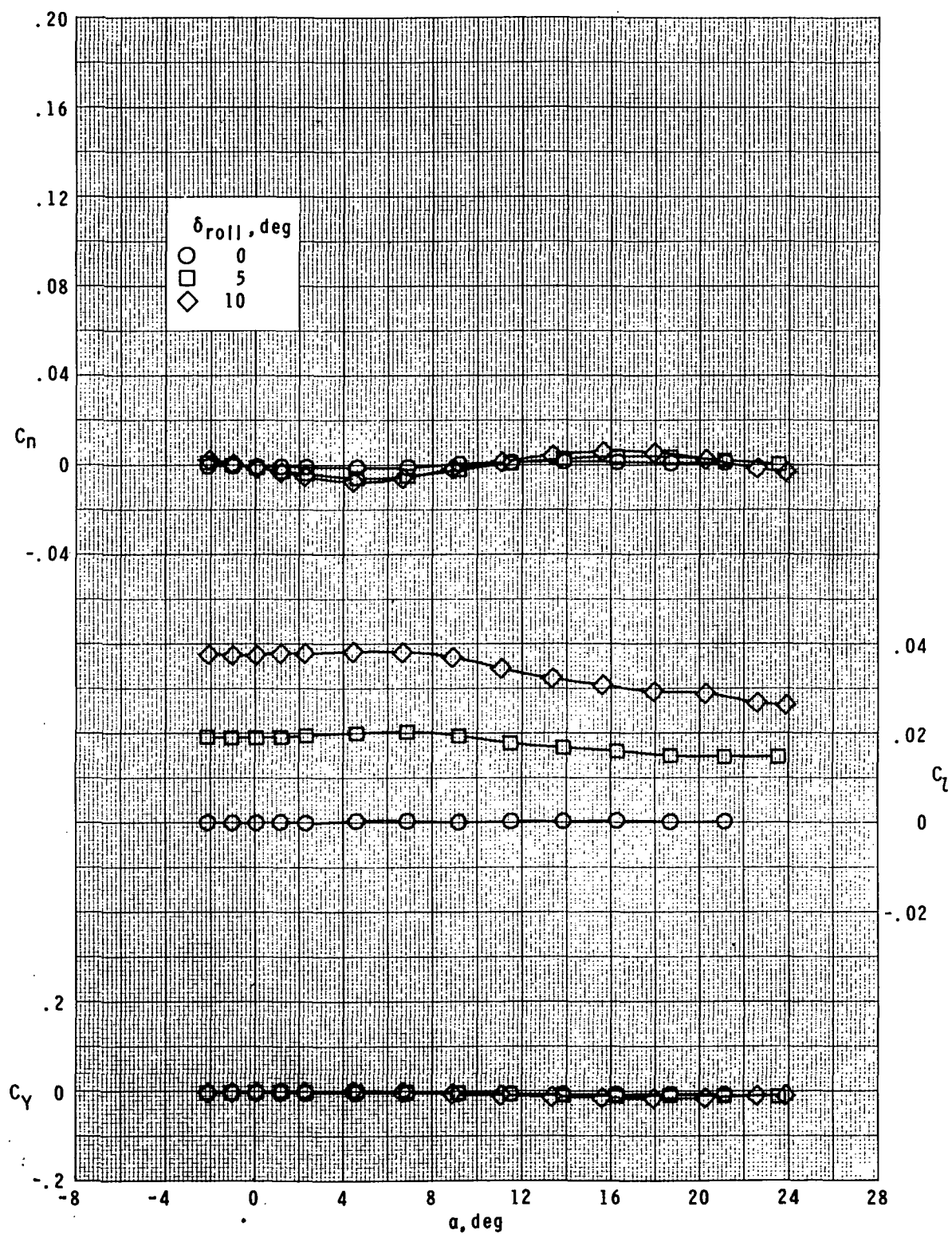
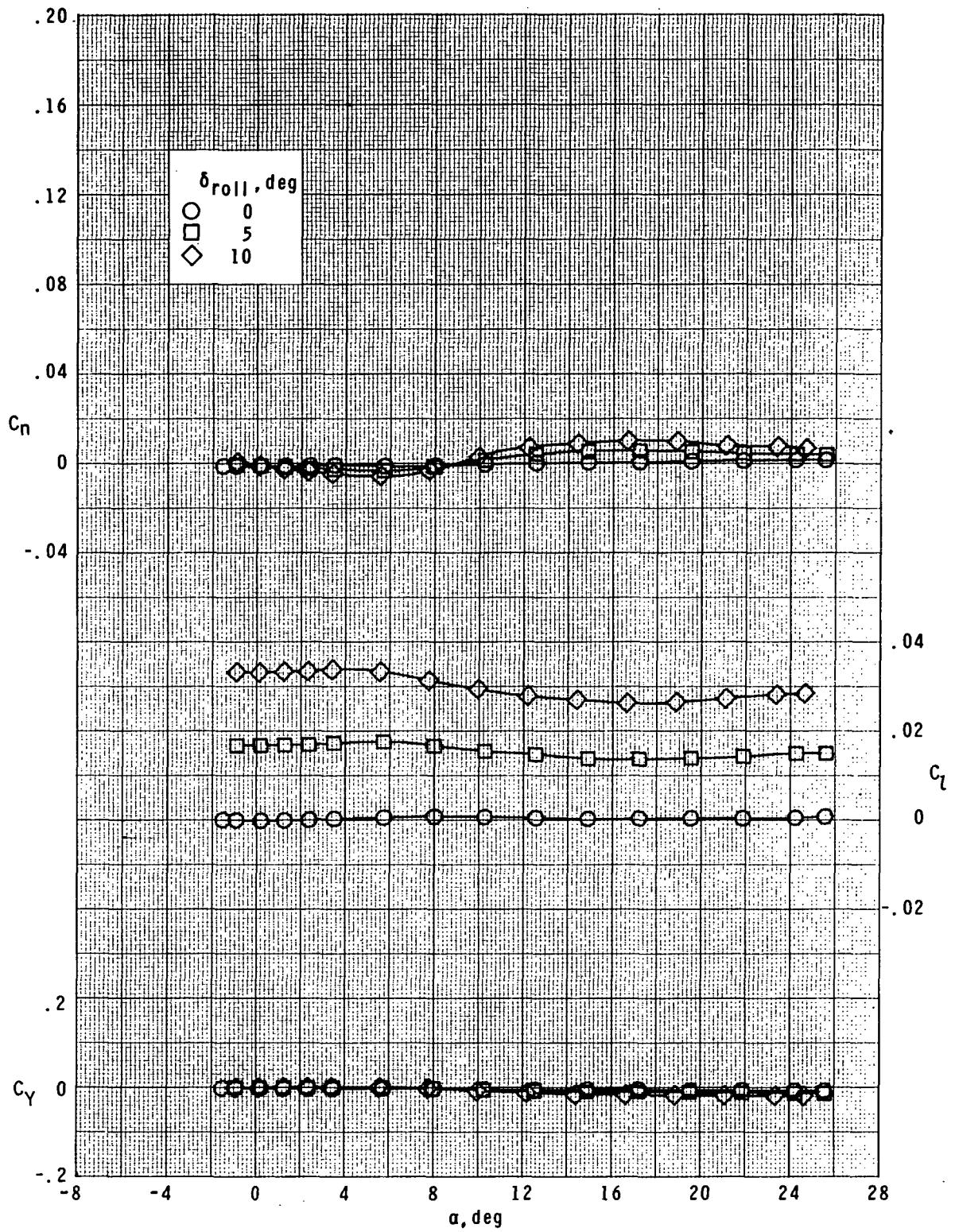


Figure 15.- Summary of lateral- and directional-stability parameters at $\alpha \approx 0^\circ$.



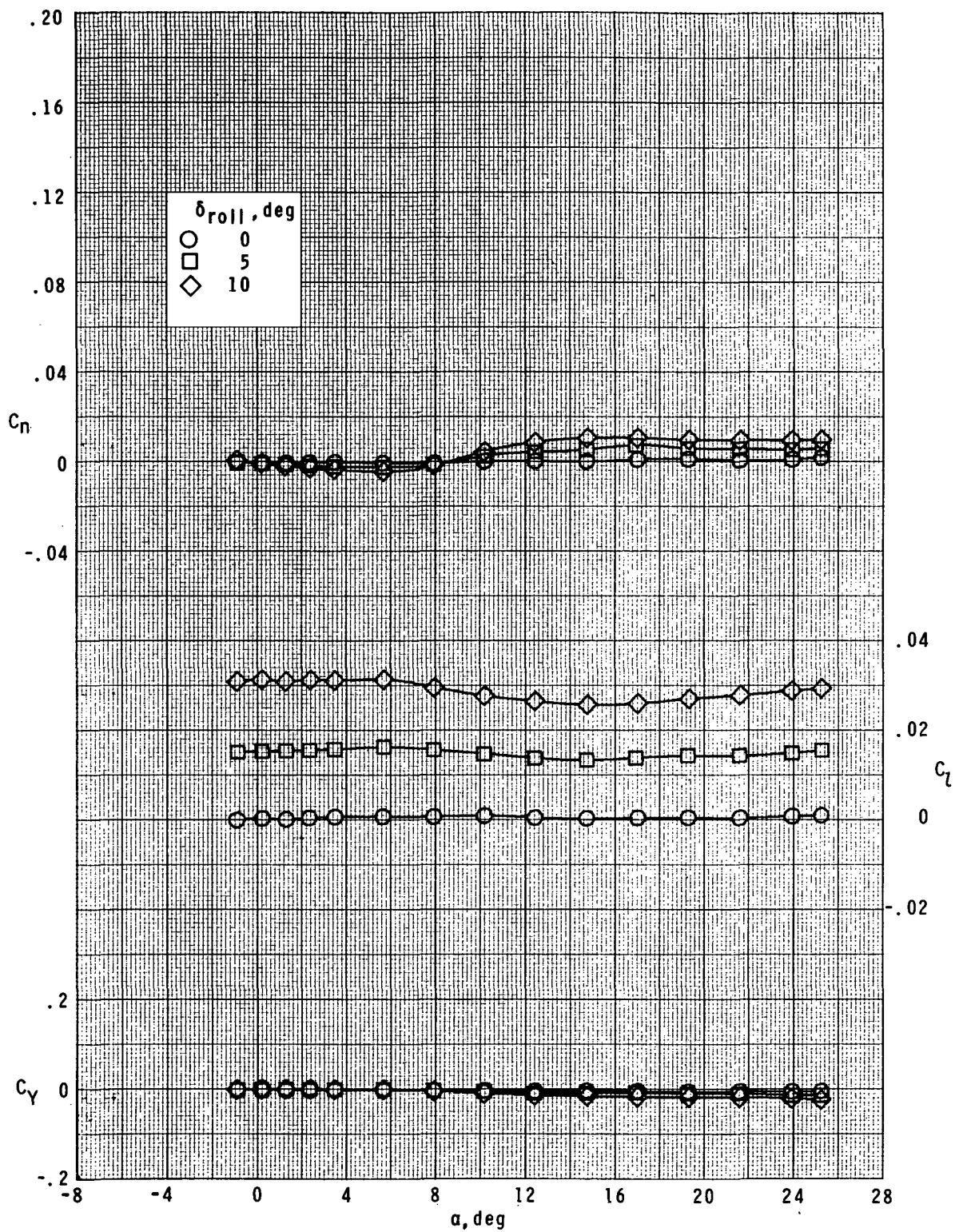
(a) $M = 1.70$.

Figure 16.- Roll-control characteristics of low-profile tail configuration.



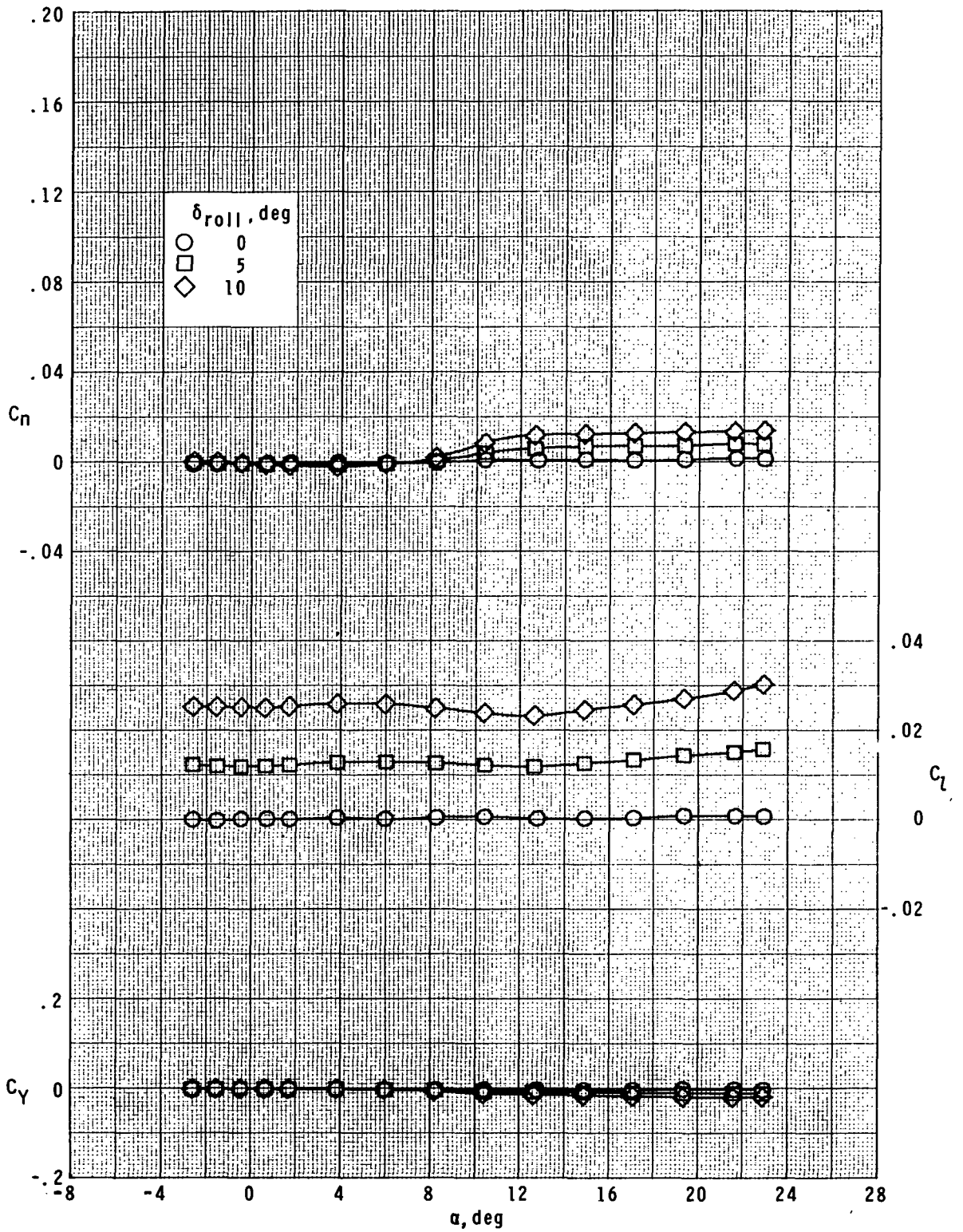
(b) $M = 2.16$.

Figure 16.- Continued.



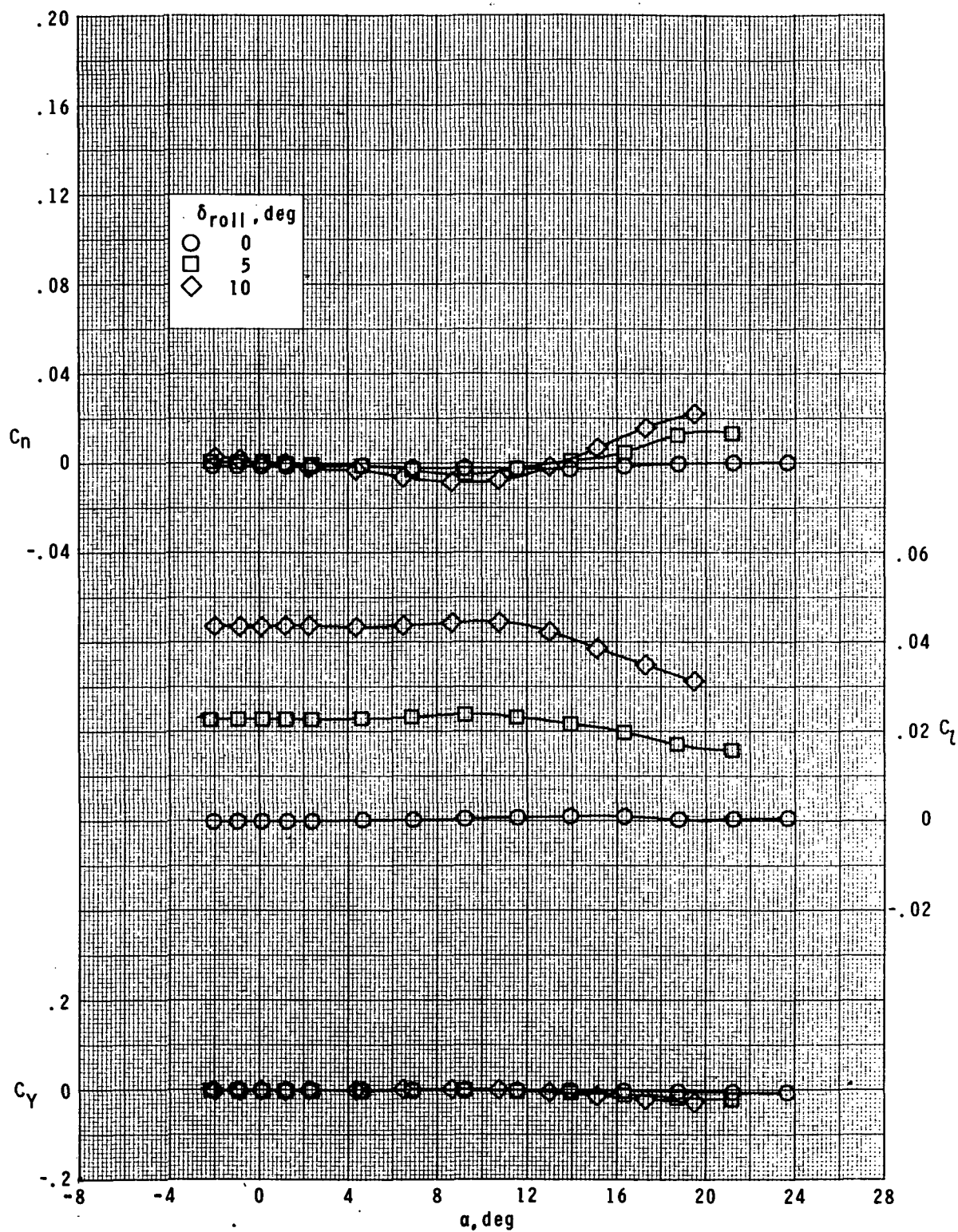
(c) $M = 2.36$.

Figure 16.- Continued.



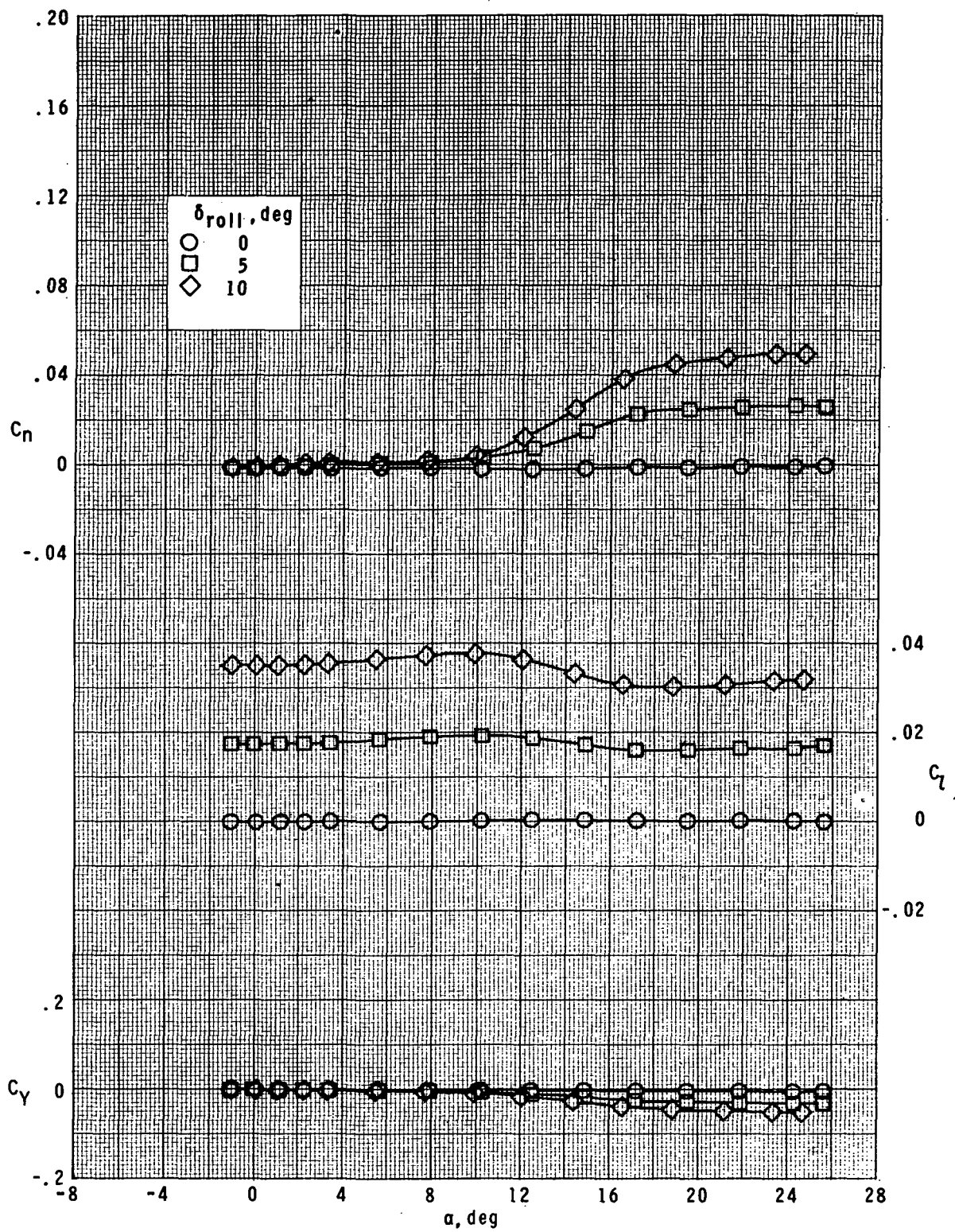
(d) $M = 2.86$.

Figure 16.- Concluded.



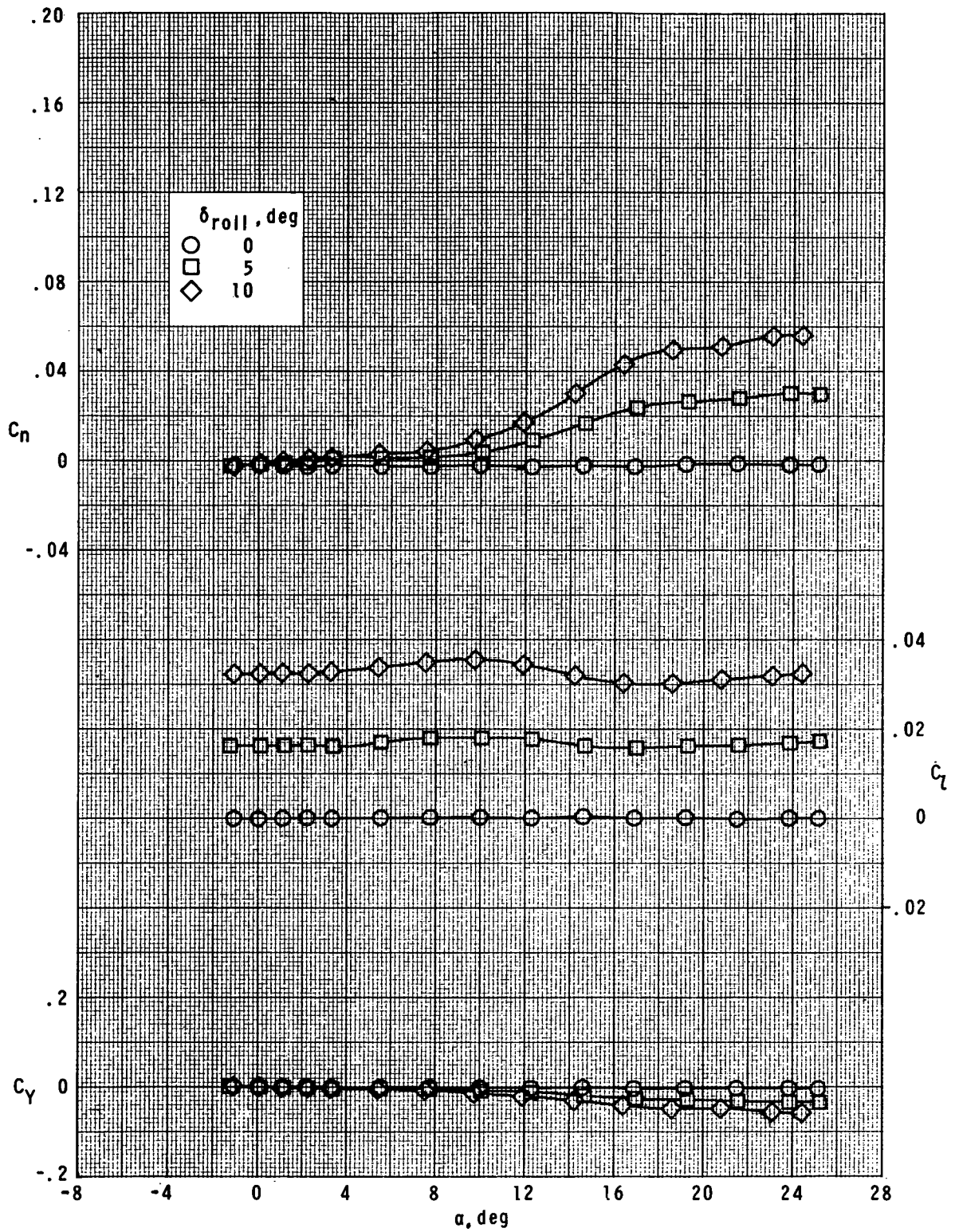
(a) $M = 1.70$.

Figure 17.- Roll-control characteristics of conventional-cruciform tail configuration.



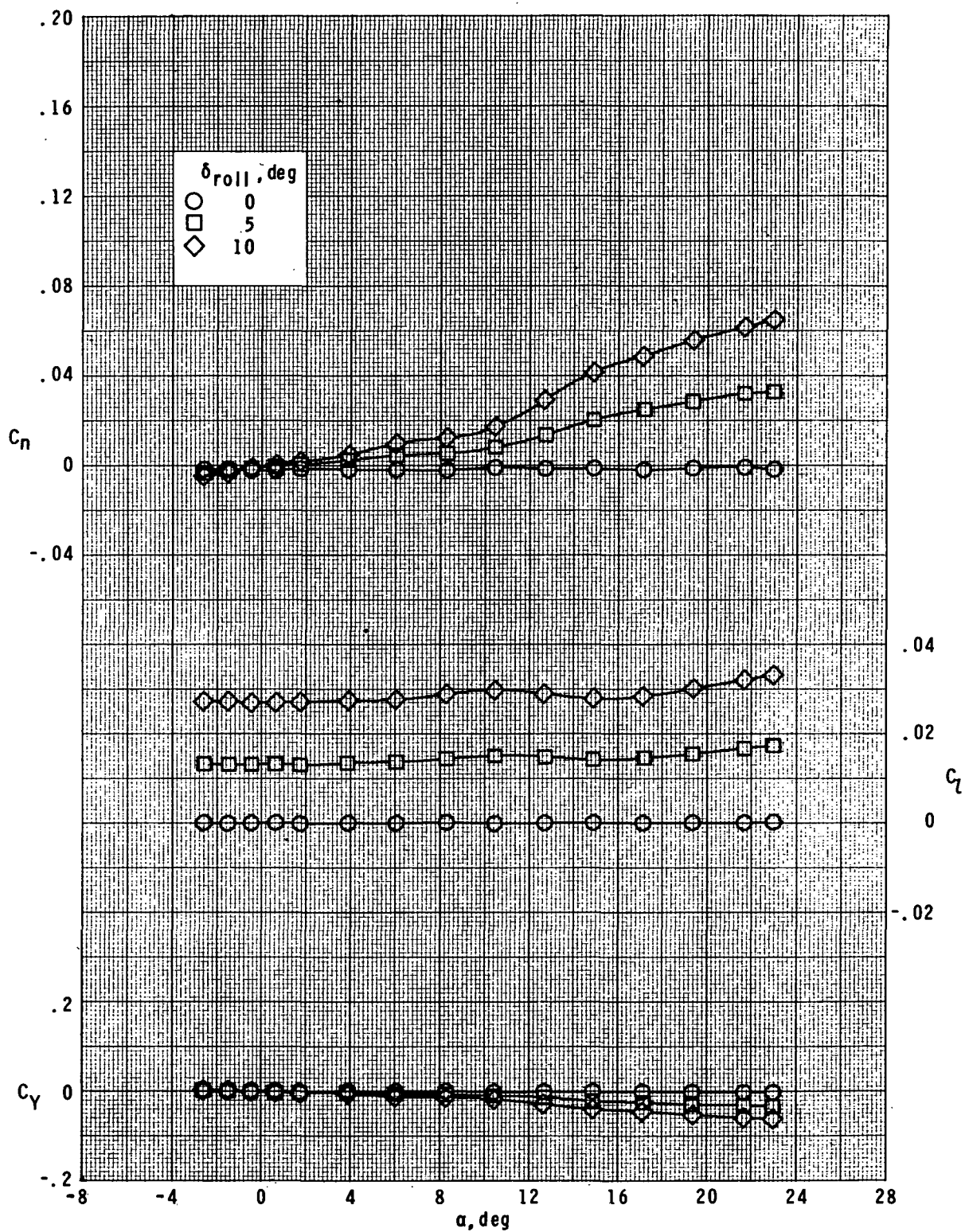
(b) $M = 2.16$.

Figure 17.- Continued.



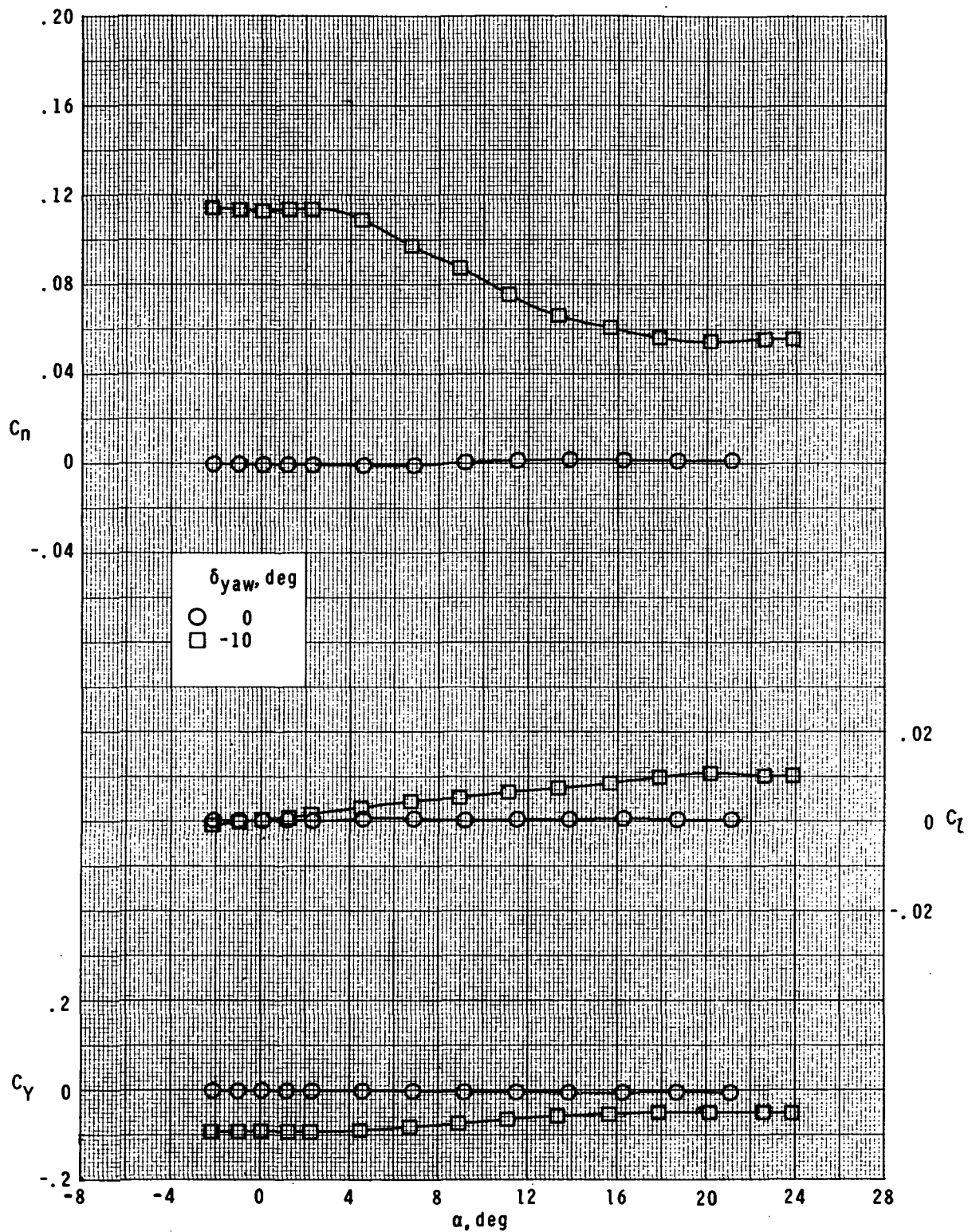
(c) $M = 2.36$.

Figure 17.- Continued.



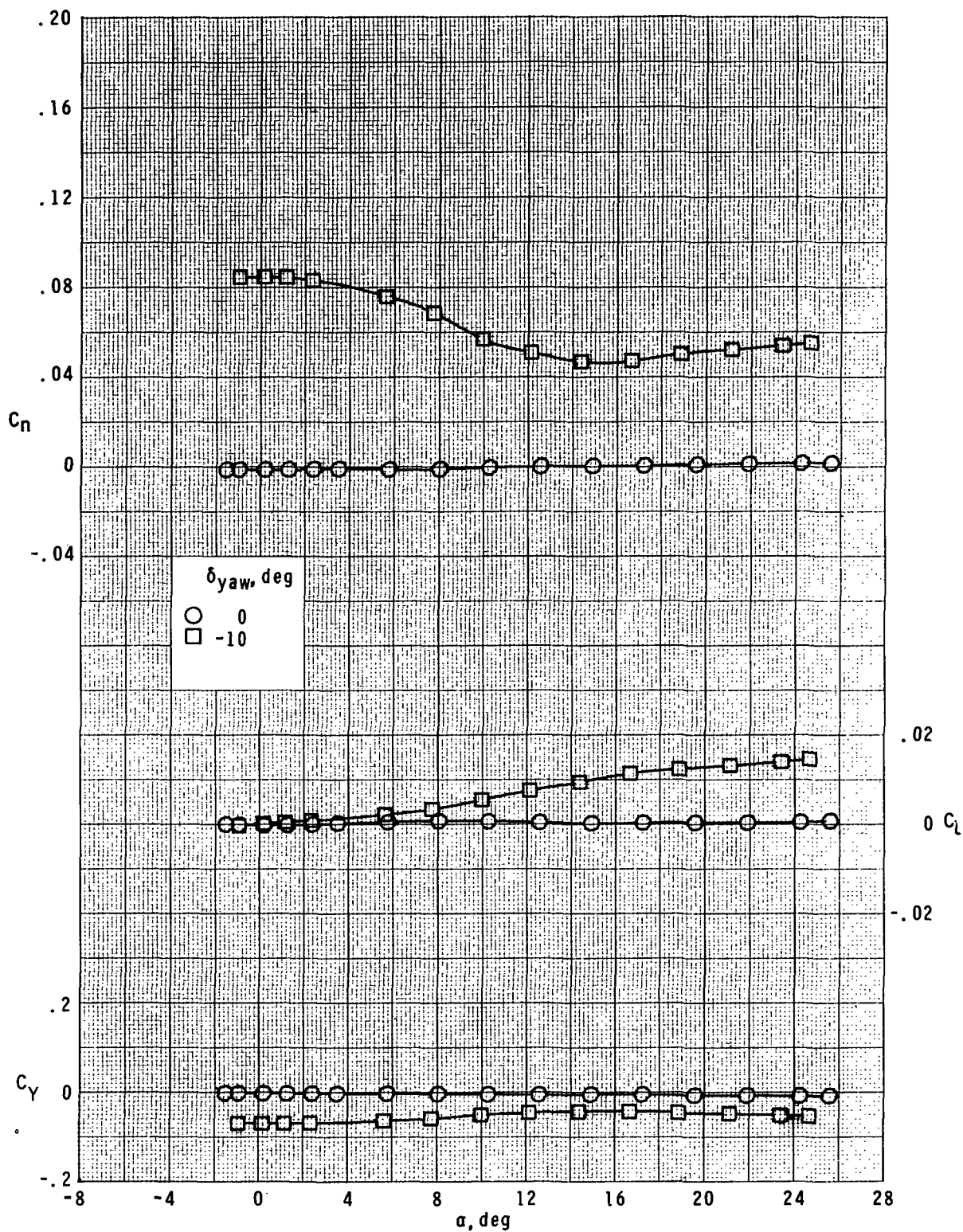
(d) $M = 2.86$.

Figure 17.- Concluded.



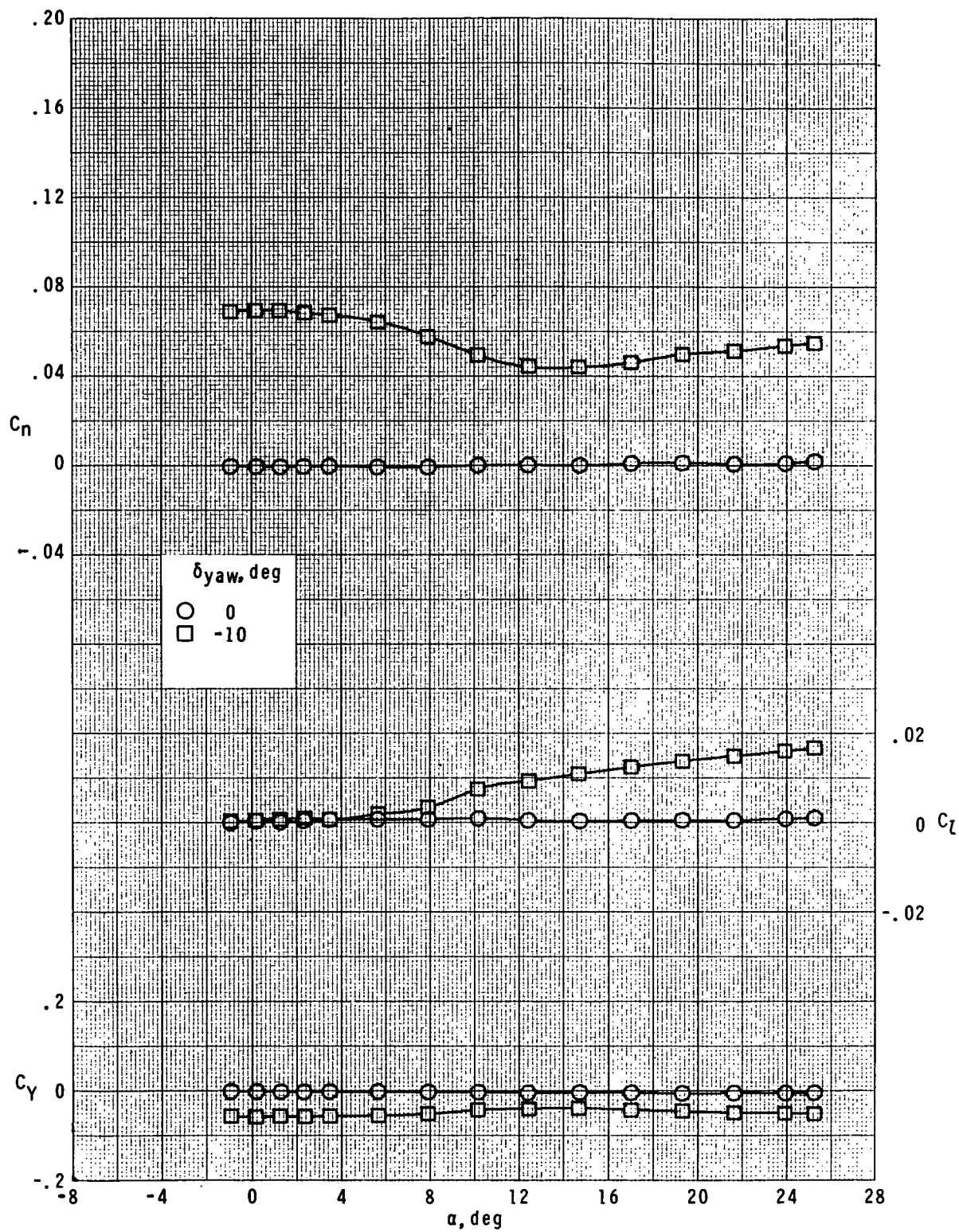
(a) $M = 1.70$.

Figure 18.- Yaw-control characteristics of low-profile tail configuration.



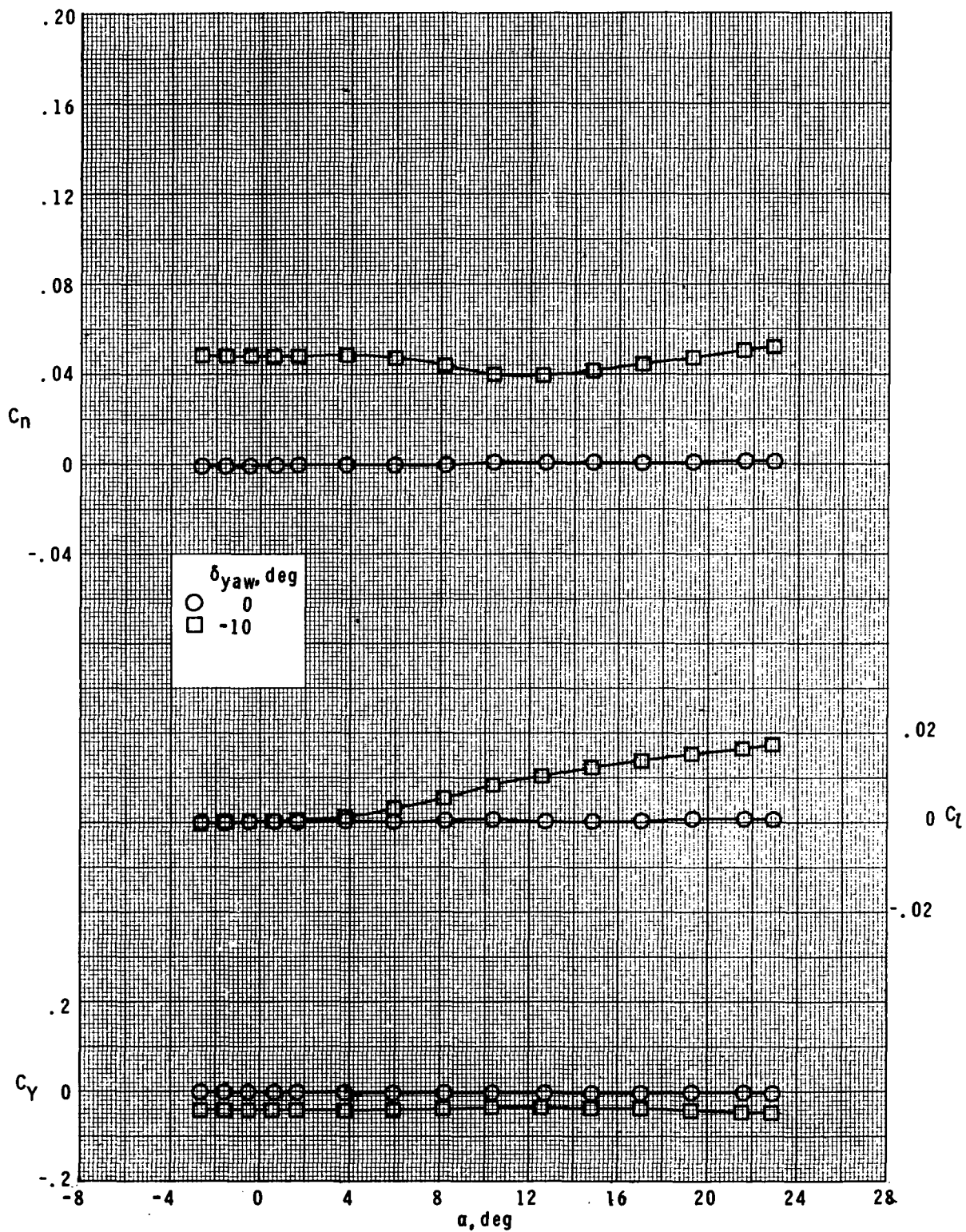
(b) $M = 2.16$.

Figure 18.- Continued.



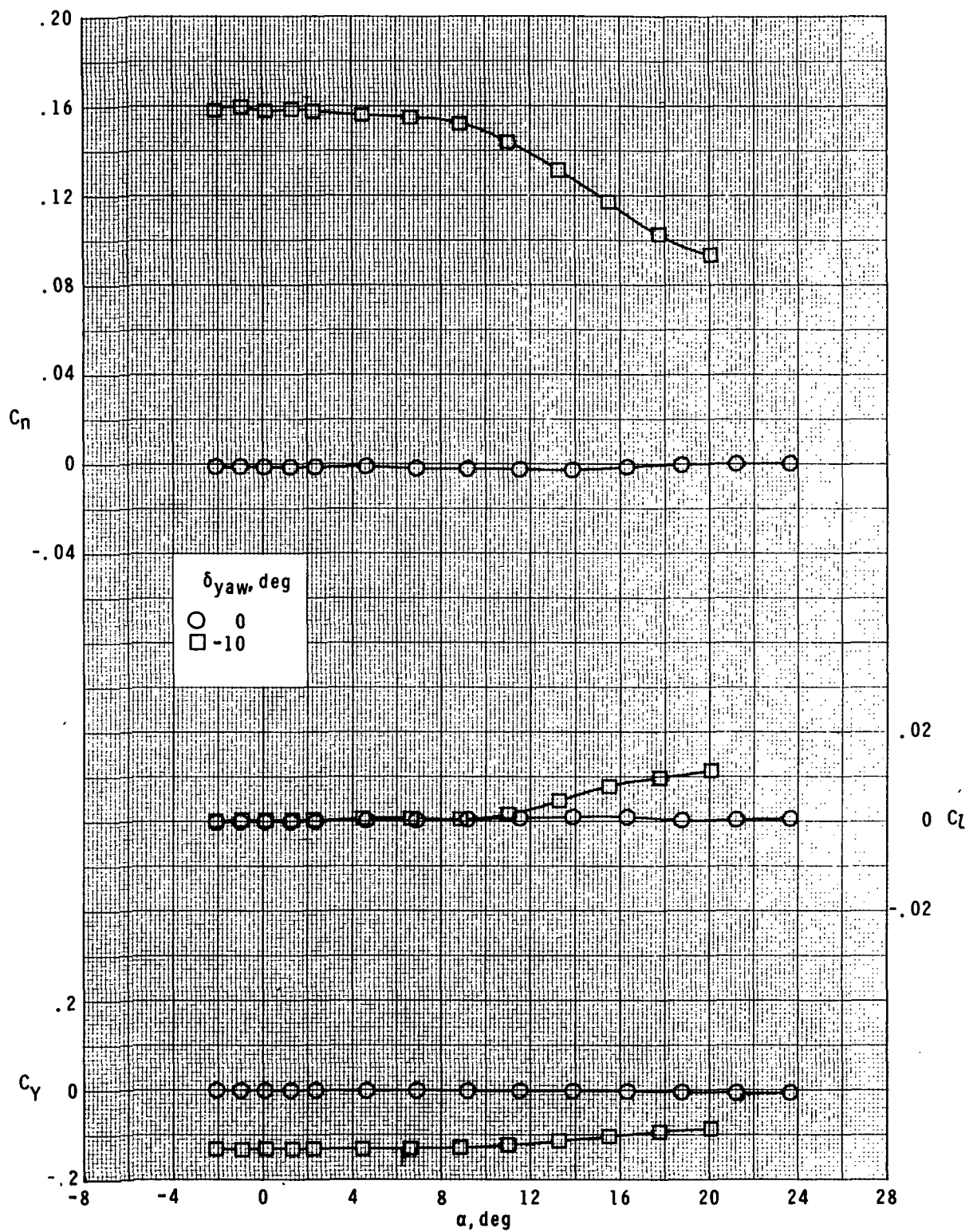
(c) $M = 2.36$.

Figure 18.- Continued.



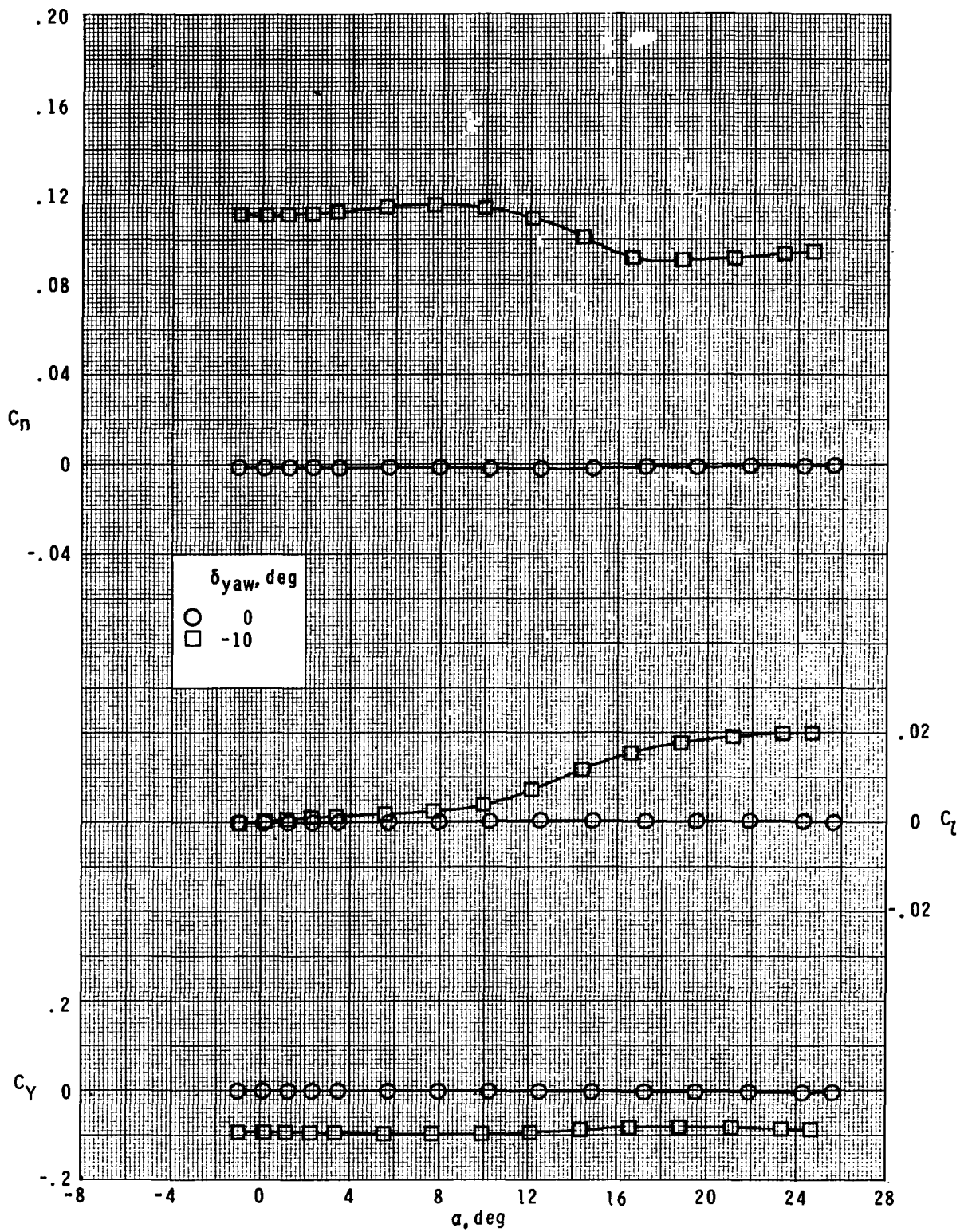
(d) $M = 2.86$.

Figure 18.- Concluded.



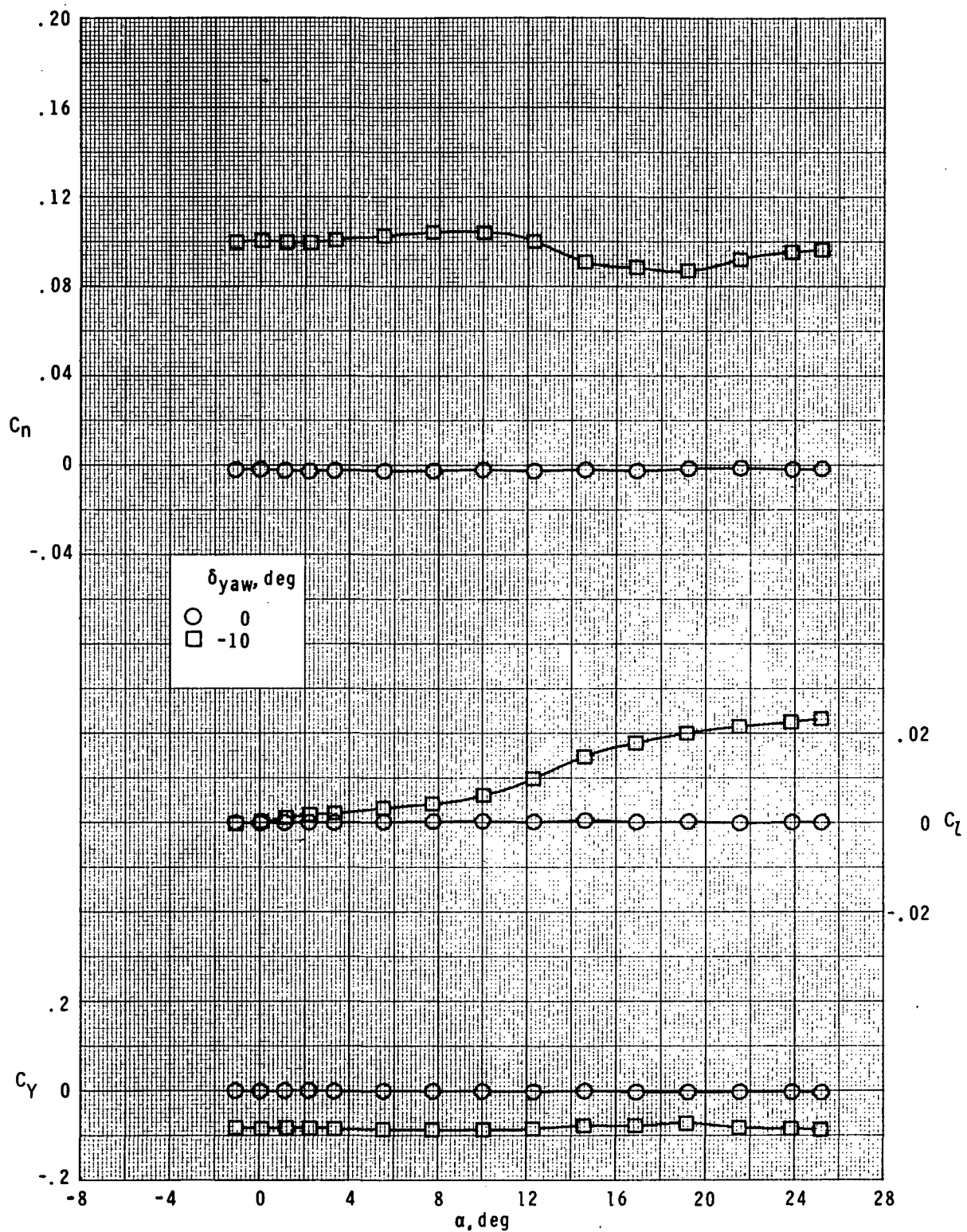
(a) $M = 1.70$.

Figure 19.- Yaw-control characteristics of conventional-cruciform tail configuration.



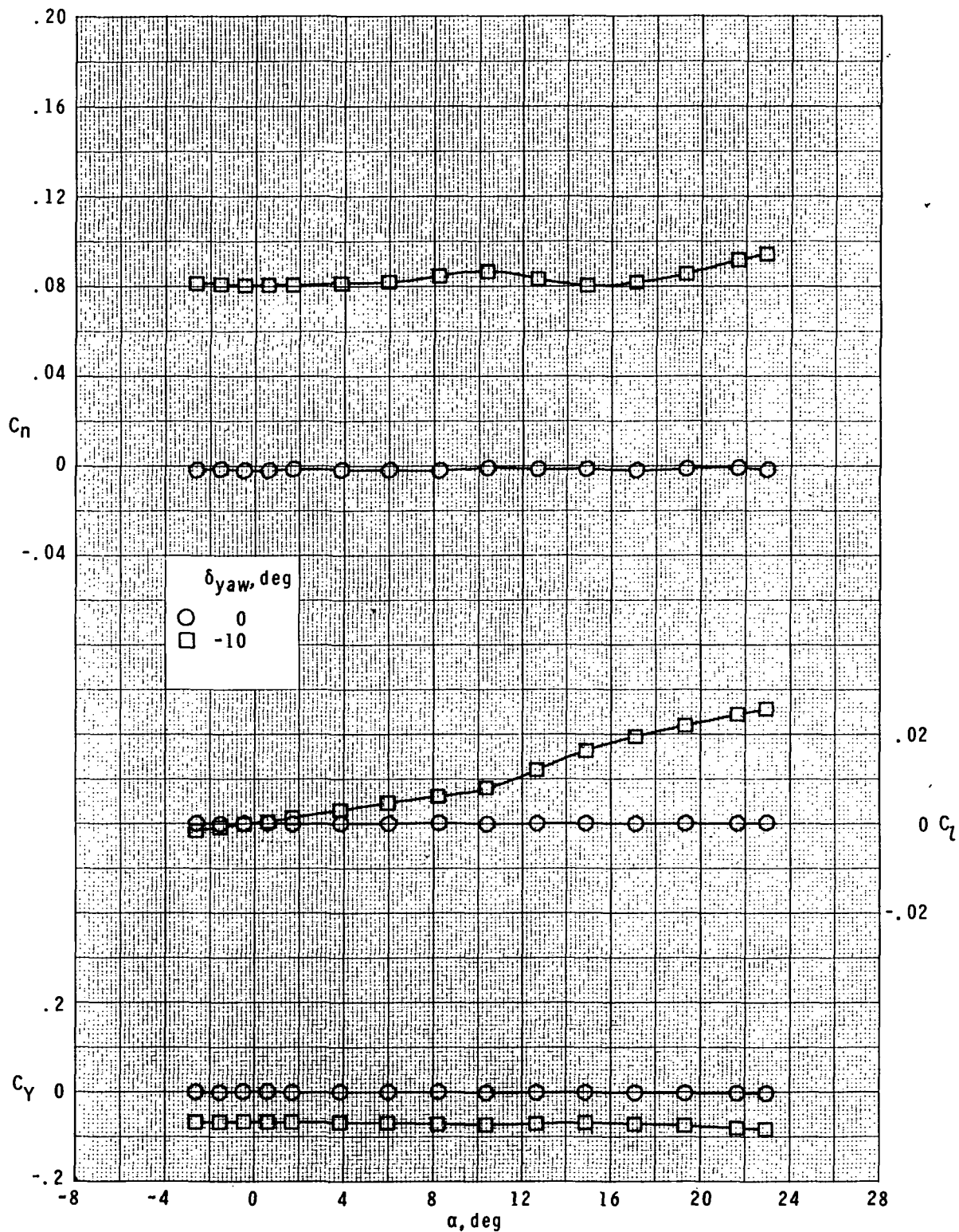
(b) $M = 2.16$.

Figure 19.- Continued.



(c) $M = 2.36$.

Figure 19.- Continued.



(d) $M = 2.86$.

Figure 19.- Concluded.

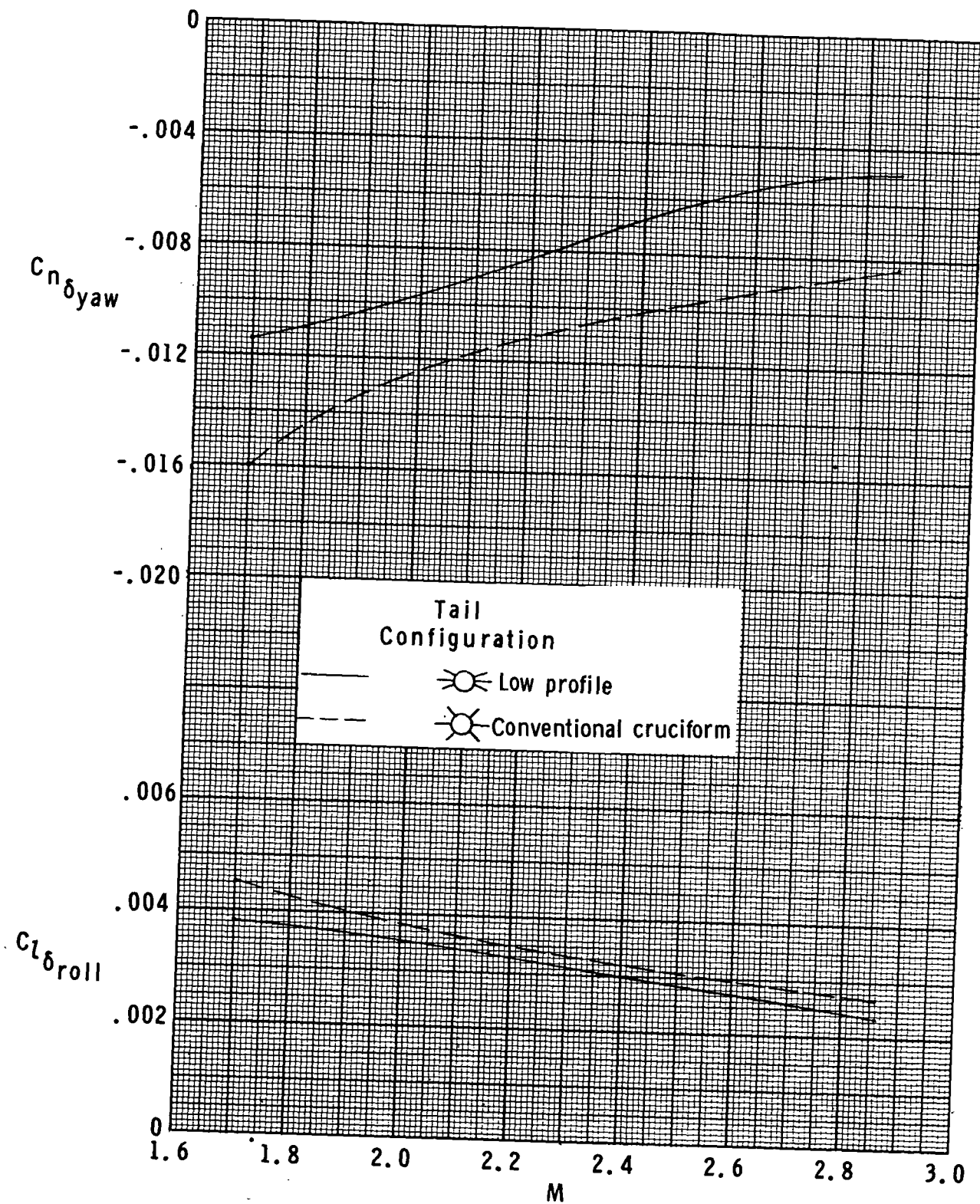


Figure 20.- Summary of roll- and yaw-control characteristics at $\alpha \approx 0^\circ$.



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—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

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